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Page 1 of 1

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				Description of the				
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				Area				

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SUBSURFACE CONDITIONS DESCRIPTION OF THE B-BX-BY WASTE MANAGEMENT AREA

M. I. Wood, Fluor Hanford, Inc., for T. E. Jones, CH2MHill Hanford Group
R. Schalla, B. N. Bjornstad, and S. M. Narbutovskih, PNNL
Richland, WA 99352
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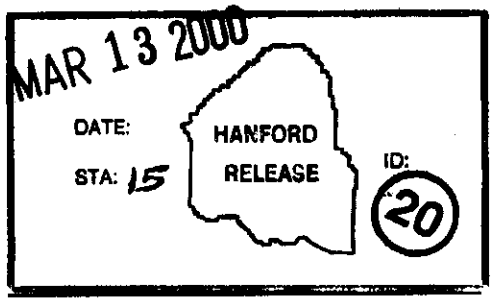
Abstract: This document provides a discussion of the subsurface conditions relevant to the occurrence and migration of contaminants in the vadose zone and groundwater underlying the 241-B, -BX, and -BY tank farms. This document provides a concise summary of existing information in support of characterization planning. This document includes a description of the available environmental contamination data and a limited, qualitative interpretation of these data.



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Date Published
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CH2MHILL
Hanford Group, Inc.
Richland, Washington

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC06-99RL14047

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M. I. Wood
Fluor Hanford, Inc.

T. E. Jones
CH2M Hill Hanford Group, Inc.

R. Schalla
B. N. Bjornstad
S. M. Narbutovskih
Pacific Northwest National Laboratory

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TERMS

CFR	*Code of Federal Regulations*
DCRT	double-contained receiving tank
DQO	data quality objective
DWS	drinking water standards
HEIS	Hanford Environmental Information System
Hf/PPu(?)	Hanford formation/Plio-Pleistocene unit (?)
ITS	in-tank solidification
LLBG	low-level burial ground
NGS	National Geodetic Survey
Qfg	Quarternary flood gravels
RCRA	*Resource Conservation and Recovery Act of 1976*
SST	single-shell tank
TBP	tributyl phosphate
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
WAC	*Washington Administrative Code*
WMA	Waste Management Area

SUBSURFACE CONDITIONS DESCRIPTION OF THE B-BX-BY WASTE MANAGEMENT AREA

1.0 INTRODUCTION

This document, *Subsurface Conditions Description of the B-BX-BY Waste Management Area*, discusses the subsurface conditions relevant to the occurrence and migration of contaminants in the groundwater underlying the B, BX, and BY tank farms. These tank farms, located in the 200 East Area of the Hanford Site, make up the B-BX-BY Waste Management Area (WMA). This document describes the available environmental contamination data and contains a limited, qualitative interpretation of the data as they apply to contaminant behavior.

1.1 BACKGROUND

Figure 1-1 shows the general location of the B-BX-BY WMA, and some other facilities in the 200 East Area. To facilitate *Resource Conservation and Recovery Act of 1976* (RCRA) groundwater monitoring programs, the B, BX, and BY tank farms were grouped into a WMA. Figure 1-2 provides more detail on the B-BX-BY WMA and surrounding area. Figure 1-2 also shows liquid discharge sites used extensively in tank farm operations (e.g., BX trenches and BY cribs) and active RCRA groundwater monitoring wells. Recent groundwater chemistry data from these wells suggest that tank waste has reached the unconfined aquifer from B-BX-BY WMA sources. These data are summarized in Chapter 3.

Because a connection between B-BX-BY WMA sources and groundwater contamination has been made, the Washington State Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) negotiated the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Change Control Form M-45-98-03 (Ecology et al. 1999). The proposed Tri-Party Agreement milestones mandate a series of activities addressing the B-BX-BY WMA. The goal of the activities is to determine the need for corrective action to mitigate the impact of contamination from single-shell tanks (SST) on the surrounding environment. One of the first significant efforts in this process is to complete additional characterization of current contamination conditions in the subsurface underlying the B-BX-BY WMA. Spectral gamma baseline data have been collected from all drywells in the three tank farms. Summary reports are available for the BX and BY tank farms; the B tank farm summary report is being developed. Information generated by these and future characterization activities will support waste management decisions for interim corrective measures, SST waste retrieval, and SST closure.

1.2 PURPOSE

Within the context of the characterization and evaluation program, this document fulfills several purposes. In the immediate future, a data quality objective (DQO) process will be convened to plan characterization activities for the B-BX-BY WMA, particularly the vadose zone. Given the numerous vadose zone and possibly relevant groundwater contamination events that have occurred in the B-BX-BY WMA, several characterization activities clearly are

Figure 1-1. Location Map of the B-BX-BY Waste Management Area and Related Facilities.

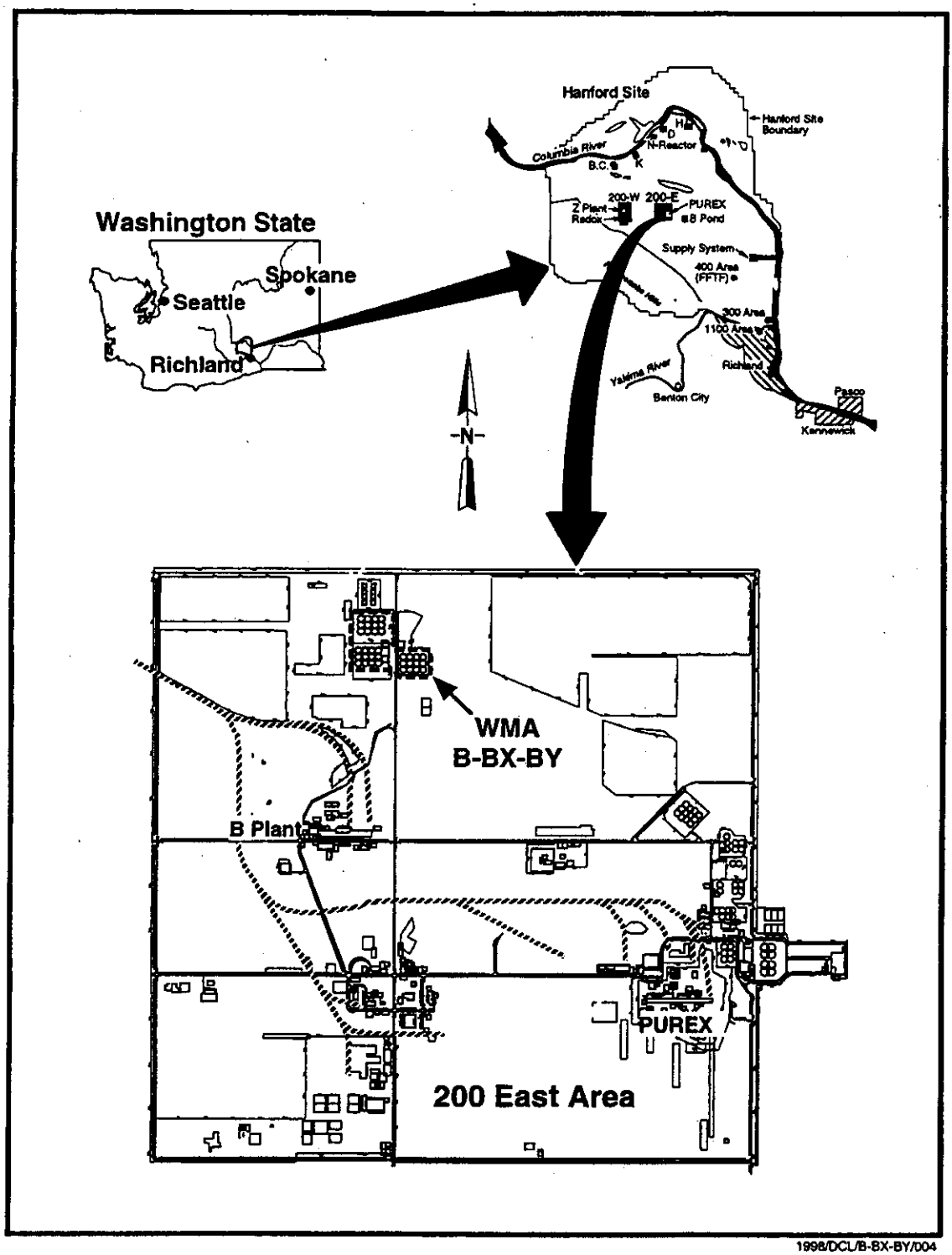
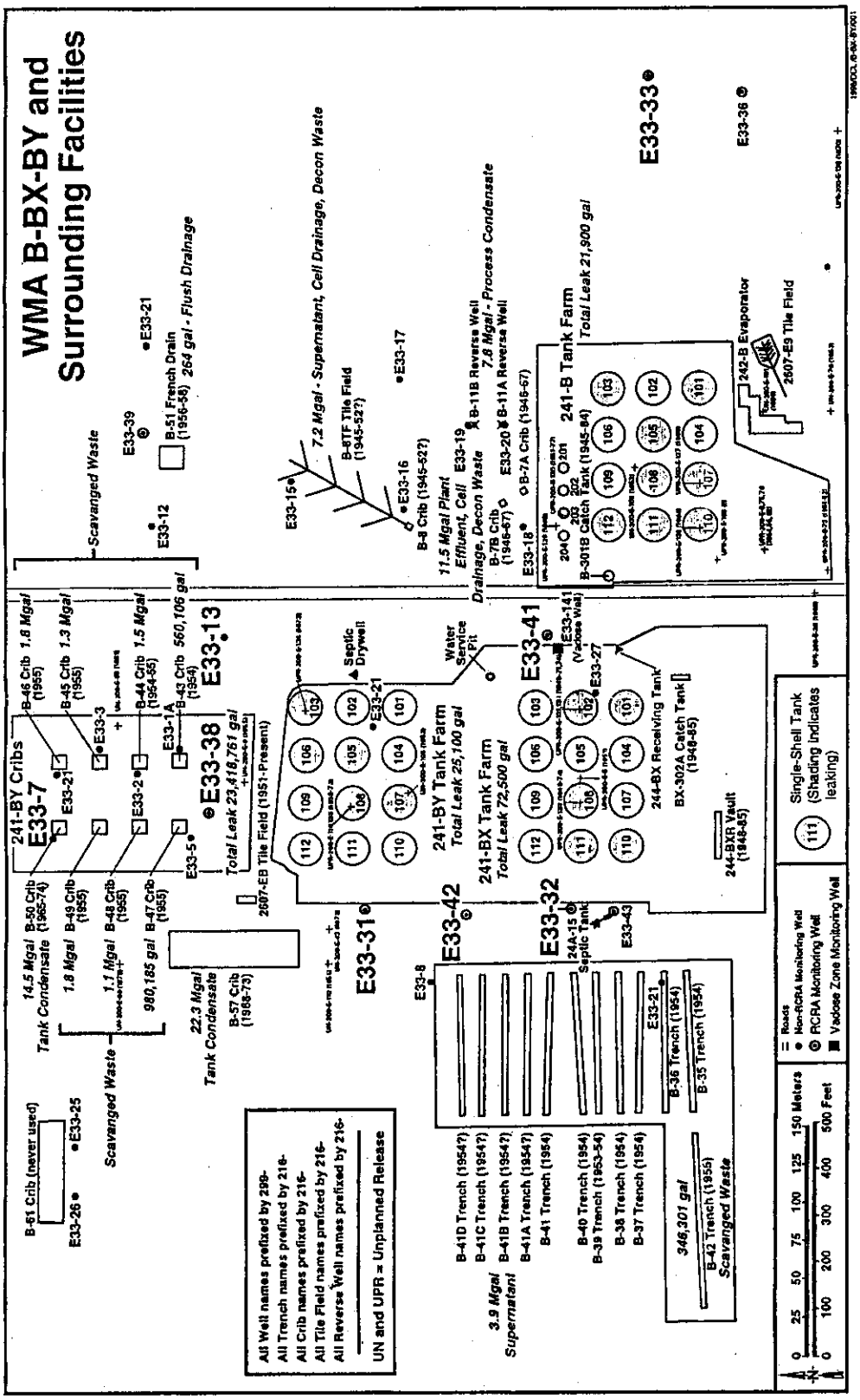


Figure 1-2. The B-BX-BY Waste Management Area and Surrounding Facilities.



plausible. Obviously, an efficient characterization approach is needed that adequately evaluates the WMA. To aid in selecting an approach, characterization is focused on site-specific data that define the occurrence and migration of contaminants within the system to date. This document includes a concise description and limited interpretation of these critical data. A systematic description of the environmental conditions affecting contaminant migration still is needed to identify data gaps, recognize significant relationships among different data types, and organize data inputs to contaminant migration models. This document provides a framework for completing a systematic description as more data are collected, interpreted, and integrated with currently available information.

1.3 SCOPE

The first part of this document describes the two primary components of the subsurface condition database: the physical setting of the B-BX-BY WMA and the contaminants contained within the WMA. Chapter 2 describes the physical setting, which includes the tank farm infrastructure, geology, hydrology and infiltration mechanisms, and geochemistry. The tank farm infrastructure description emphasizes those parts of the system that allowed fluids to discharge into the soil column and the time periods during which these parts were operational. The geology description emphasizes the impact of the geologic strata on fluid movement. The hydrology and infiltration discussion emphasizes infiltration mechanisms, infiltration history, and hydrologic properties of the geologic strata that control fluid movement. The geochemistry section emphasizes the characteristics that control contaminant movement, particularly in relation to fluids.

The second component of the subsurface characterization database is the description of contaminant occurrences and movement within the vadose zone and the unconfined aquifer. This is presented in Chapter 3. First, contamination events are summarized to orient the reader to the historical sequence. This is important because of the multiple fluid discharges in and near the B-BX-BY WMA and multiple occurrences of contamination currently observed in the unconfined aquifer underlying the B-BX-BY WMA. Second, the synthesis of the historical and spectral gamma database for the BX and BY tank farms is summarized. These data are unique because of their extent, both temporally and spatially. Synthesis of spectral and historical gamma data for the B tank farm are being documented, but are not yet available. The overview demonstrates the observed spatial variability of contaminant concentration and provides the most comprehensive indication of the diversity among various contaminating events. The remainder of the discussion in Chapter 3 is organized by specific sources or similar types of sources. The key data in this discussion include tank waste inventory and chemistry information derived from process history, the corroborating gamma data, and soil sample data where available.

Chapter 4 contains a brief qualitative integration of the data and relates the data to a conceptualization of the contamination events. Because the events are diverse, database interpretations are given for each specific contaminating occurrence or type of occurrence.

Key uncertainties and data gaps that are important to understanding potential future contamination of the unconfined aquifer are identified in Chapter 5. Chapter 5 also provides recommendations for resolving these uncertainties.

Five appendices also are provided. Appendix A contains the text of the B-BX-BY WMA historical summary document (Williams 1999) and the description of the metal waste discharge from tank BX-102 (General Electric Company 1951). Appendix B provides supporting geologic data. Appendix C provides supporting hydrologic data. Appendix D is a letter report on waste site-specific sorption experiments. Appendix E summarizes the analyses of gamma logging data.

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2.0 PHYSICAL SETTING

2.1 B-BX-BY WMA INFRASTRUCTURE AND OPERATIONS HISTORY

This section discusses the infrastructure and briefly summarizes the B-BX-BY tank farm operations history, including the use of ancillary equipment and nearby cribs, trenches, and wells. A more detailed historical review is provided in Williams (1999). Excerpts from this report are provided in Appendix A. The section also identifies those elements of the infrastructure known or suspected to have discharged fluids to the vadose zone, along with elements that remain capable of future discharges.

2.1.1 B-BX-BY WMA Infrastructure

The B-BX-BY WMA consists of three tank farms, waste transfer lines, leak detection systems, and other miscellaneous equipment (Figure 1-2). Additional facilities that have been used during B, BX, and BY tank farm operations are located just outside the WMA boundaries. These facilities include numerous cribs, trenches, and reverse wells located to the east, north, and west of the B-BX-BY WMA and the 242-B Evaporator facility, located just south of the B tank farm. Discharge to cribs, trenches, and reverse wells is discussed in more detail in Section 2.3. In addition, the B pond, located approximately 3.5 km east of the B-BX-BY WMA, received about 283 billion gal[1] of slightly contaminated water, a fraction of which included fluids generated by B-BX-BY tank farm operations. The large additions of water to the B pond significantly altered groundwater flow patterns under the B-BX-BY WMA. A number of active or abandoned water lines cross the B-BX-BY WMA. Leaks from these water lines could potentially enhance contaminant migration toward the unconfined aquifer.

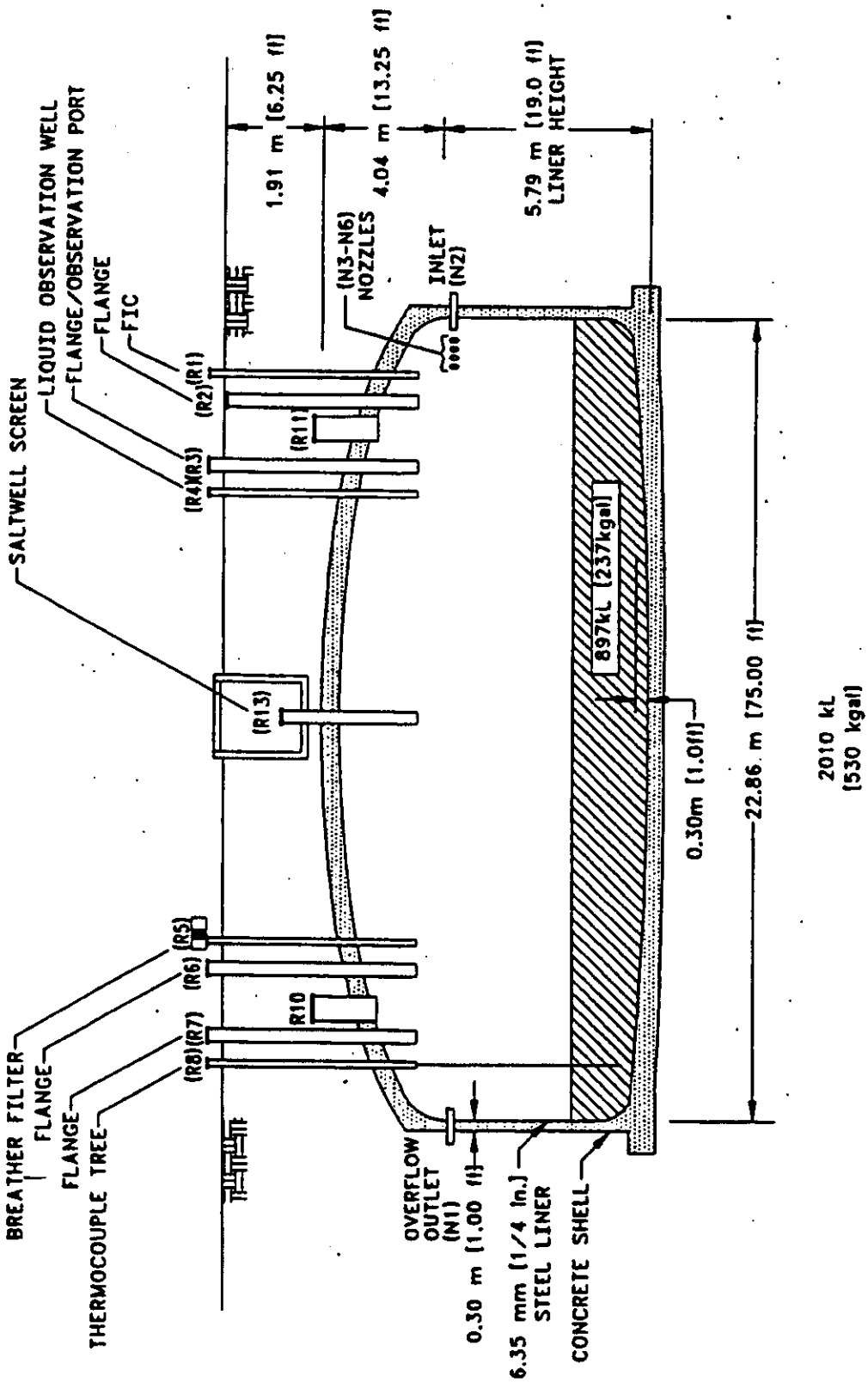
2.1.2 Operation History

The B-BX-BY tank farm complex has received waste generated by a variety of major chemical processing operations. The initial operation was the bismuth phosphate plutonium extraction process that generated large amounts of waste requiring storage and, frequently, disposal. The B tank farm was built in 1943 to 1944 and consists of twelve 23 m (75-ft)-diameter tanks with nominal 535,000 gal storage capacity. B tank farm also contains four tanks that are 6.1 m (20 ft) in diameter and hold 55,000 gal each. A cross section of the 241-B-111 tank in B tank farm is provided in Figure 2-1. This cross section also represents the other primary tanks in the B tank farm and the tanks in the BX and BY tank farm. However, BY tanks are about 8.5 m (28 ft) tall instead of the 5.79 m (19 ft) shown in the diagram. Note the depth of the inlet and outlet ports about 5.8 m to 6 m (19 to 20 ft) below the surface.

---

[1] Tank capacities and leak volumes have historically been measured in gallons and are still being reported in gallons in the Hanlon reports. Therefore, tank capacities and leak volumes will be measured in gallons in this document.

Figure 2-1. Cross Section and Schematic for Tank 241-B-111.



Multiple sets of pipe lines were installed to assist the various operations described in the following paragraphs. As shown in Appendix A, Figure A-1, the initial waste transfer piping system in the B tank farm was rather simple. The 12 tanks were divided into 4 sets of 3 tanks each (e.g., tanks B-101, B-102, and B-103). The sets are arranged in parallel rows running north and south. The tanks are connected in series by waste transfer piping. The southernmost tank in each series (e.g., B-101)received waste first. When waste levels rose above the height of the open waste transfer line, waste cascaded into the next tank by gravity feed. As shown in Figure A-2, the waste transfer systems in other tank farms were similarly constructed except that each three-tank cascade in the BX farm was connected to a three-tank cascade in the BY farm, thereby making four parallel six-tank series. For example, waste placed in tank BX-101 could end up in tank BY-103.

In 1945, the B tank farm tanks began receiving bismuth phosphate waste from B Plant. Because of limited tank space, intentional discharge of bismuth phosphate waste to the soil column began in 1946 in cribs B-7A and B-7B. From 1947 through 1949, BX and BY tank farms and other cribs, notably 216-B-8, were constructed to handle the large volumes of generated waste. Each tank farm contains 12 tanks. BX tanks have a storage capacity of 535,000 gal and BY tanks have a storage capacity of 758,000 gal.

From 1948 through 1951, the 216-B-8 crib was the primary discharge facility, receiving approximately 713,265 gal of waste. To improve liquid reduction, the 242-B evaporator was built in 1951 and began shipping condensate to reverse wells 216-B-11A and 216-B–11B. However, the evaporator process was diverted to a different waste stream and the last large scale disposal 351,350 gal of bismuth phosphate waste into the BX trenches occurred in 1954.

The next large-scale processing operation to use the B, BX, and BY tank farms was uranium recovery operations. Substantial amounts of uranium were present in the B, BX, and BY tanks from the initial waste called metal waste produced by the bismuth phosphate process. Subsequently, a need arose for uranium and the most convenient source was the metal waste in the tanks. Beginning in 1952, metal waste was sluiced from the tanks and sent to U Plant where uranium was extracted. TBP waste generated from this process was returned to the 242-B Evaporator to reduce the waste volume. A ferrocyanide treatment also was used to remove excess ^{137}Cs and ^{90}Sr. The waste ultimately was disposed of in the BY cribs and BX trench 216-B-42 in 1954 and1955. In all, about 9,000,000 gal were discharged to the BY cribs and 400,000 gal were discharged to BX trench 216-B-42.

Following completion of the uranium recovery program, concern about potential tank leakage grew and a decision was made to remove excess liquid from the tanks. Consequently, the In-Tank Solidification Operations (ITS) program was initiated. The ITS program consisted of heating the air inside the tanks to promote evaporation. ITS#1 used heated air circulated through tanks 241-BY-101 and 241-BY-102 beginning in 1965. As modification ITS#2, heaters were installed in the tanks beginning in 1968. This program lasted until 1974 when a decision was made to use saltwell pumping, a more efficient method of reducing liquid. Condensate from ITS#1 1,558,615 gal was sent to BY crib 216-B-50 and condensate from ITS#2 2,219,045 gal was sent to BY crib 216-B-57.

The saltwell pumping program replaced the ITS program in 1975 to accelerate removal of all excess liquid in the tanks as the first step in achieving a condition known as interim stabilization. Initially, pumped tank liquid passed through tank 241-BX-104 through diversion

box 241-ER-151 to the 242-S and 242-A Evaporators. In 1983, double-contained receiver tank (DCRT) 244-BX was constructed to replace tank 241-BX-104 as the receiver for pumped tank liquids.

From 1967 to 1979, the B Plant was reactivated as an isotope recovery and storage facility. The primary focus was on recovering ^{137}Cs and ^{90}Sr from tank waste and plutonium-uranium extraction (PUREX) and reduction-oxidation (REDOX) process streams. Several waste streams were generated during this phase of B Plant operations (Agnew 1997). Some of the B Plant isotope recovery programs used organic complexing agents extensively to facilitate specific radionuclide separations (Agnew 1997). Many of the organic complexing agents ended up in the high-level waste stream coming from the B Plant. The B plant high-level waste stream and lower activity waste streams were routed to tanks in the B-BX-BY WMA.

Each tank in the B, BX and BY tank farms has shallow [24 m to 31 m (80- to 102-ft)-deep] radiation monitoring wells (drywells) installed around it as a secondary leak detection system. More than 70 monitoring wells were drilled for each tank farm. All were completed by the early 1970s. Groundwater monitoring wells also have been developed and used in crib and trench locations outside the B-BX-BY WMA to evaluate contaminant occurrence in the unconfined aquifer resulting from the intentional discharges to those locations (see Appendix A).

Finally, a number of raw and potable water lines are present in and around the B-BX-BY WMA. Leaks from these lines probably have contributed to tank waste migration in the vadose zone. Also, because of the monitoring approach that was used, only a small fraction of leaks have been reported. Individual lines were not monitored for leaks. Instead, nominal leakage during operations was assumed and system performance was maintained by modulating flow rates to maintain necessary system pressure. Leaks were reported by observation and had to be sufficiently large to saturate the surrounding soil before they were noticed. Smaller leaks would go undetected, but still could add substantial volumes of water to the soil column over time.

2.2 GEOLOGY

This section summarizes the geologic setting and presents an updated conceptual geohydrologic model of the area in the vicinity of WMA B-BX-BY. This analysis is based on 37 boreholes, listed in Table 2-1, that penetrate the unconfined aquifer within 300 m (1,000 ft) of the WMA. The locations of the boreholes are shown in Figure 2-2. The information in this section provides the framework for subsequent consideration of stratigraphic and structural controls on moisture and waste movement through the vadose zone to groundwater. Stratigraphic cross sections, a fence diagram, and isopach and structure contour maps of the suprabasalt units are included in Appendix B.

Table 2-1. Summary of Available Data for Boreholes Located Within 300 m (1,000 ft) of the B-BX-BY WMA. (2 sheets)

		State NAD83											Depth (ft. below ground surface)							Elevations (ft AMSL)						Thickness (ft)						Characterization Data						
Boring No.	Drill Method	Easting (m)	North-ing (m)	TOC (ft)	Stick-up (ft)	Surf. Elev. (ft)	Well Survey	Total Depth (ft)	Completion Date	Open Interval (ft bgs)	Depth to Water (ft)	Date of WL Measure-ment	TOB	Top Hf/PPu (?) Gravel	Top of Hf/PPu (?) Silt	Top of H3/PPU (undif.)	Top H3	Top H2	TOB	Top Hf/PPu (?) Gravel	Top Hf/PPu (?) Silt	Top H3/PPU (undif.)	Top H3	Top H2	Hf/PPu (?) Gravel	Hf/ PPu (?) Silt	H3/PPU (undif.)	H3	H2	H1	Drillers Log	Geologists Log	Geophy. Logs	Grain Size/ $CaCO_3$ (depth interval [ft.])	Moisture (depth interval [ft.])	Quality Ranking	Comments
E28-08	HT	573698	137074	672.01	1.5	670.51	NAVD 1988	315	Sep-57	*250-294*	268.77	12/4/98	295.7	?	NP	225	NA	17	374.8	?	NP	446	NA	654	?	NP	71	NA	208	17	X		NG, N, T	5-315		3	Lindsey log
E33-01A	HT	573633	137614	635.44	2.59	629.50	NAVD 1988	240	Aug-54	*215-235*	231.05	7/10/96	NR	?	NP	200	NA	25	NR	?	NP	430	NA	605	?	NP	NA	NA	175	25	X		N, D	5-115		2	
E33-02	HT	573617	137642	635.11	2.6	632.51	NAVD 1988	243	Nov-54	*220-233*	230.24	6/13/96	234.5	?	NP	185	NA	20	398.0	?	NP	448	NA	613	?	NP	50	NA	150	20	X		N, D	5-243		2	
E33-03	HT	573633	137666	633.96	2.6	631.36	NAVD 1988	236	Nov-54	*219-231*	229.16	6/13/96	231	?	NP	187	NA	83	400.4	?	NP	444	NA	?	?	NP	44	NA	104	?	X		N, D			1	
E33-04	HT	573617	137693	633.18	2.66	627.18	NAVD 1988	231	Dec-54	*215-231*	228.43	6/14/96	229	?	NP	190	NA	30	398.2	?	NP	437	NA	597	?	NP	39	NA	160	30	X		N, D	0-231		2	
E33-05	HT	573574	137607	638.03	2.56	632.10	NAVD 1988	238	Jun-55	*218-235*	235.06	5/5/99	236	?	NP	180	NA	75	396.1	?	NP	452	NA	582	?	NP	56	NA	130	50	X		NG, N, D	20-236		3	
E33-06	HT	573574	137653	631.34	2.9	628.44	NAVD 1988	238	Jun-55	*214-229*	223.81	2/4/86	229	?	NP	185	NA	50	399.4	?	NP	443	NA	578	?	NP	44	NA	135	50	X		N, D	5-215		2	
E33-07	HT	573574	137696	631.15	4.0	627.15	NAVD 1988	233	Apr-55	*215-230*	228.19	5/5/99	230	?	NP	192	NA	50	397.2	?	NP	435	NA	577	?	NP	38	NA	142	50	X		N, D	5-233		2	
E33-08	HT	573476	137448	654.29	3.6	650.69	NAVD 1988	257	Oct-53	*230-257*	251.38	5/5/99	257	?	NP	210	NA	30	393.7	?	NP	441	NA	621	?	NP	47	NA	180	30	X		N, D	5-257		2	
E33-09	HT	573647	137486	654.17	0.6	650.00	NAVD 1988	275	Jul-49	*252-262*			263	?	NP	200	NA	53	387.0	?	NP	450	NA	597	?	NP	63	NA	147	53	X			5-275		2	
E33-10	HT	573256	137258	677.02	2.86	668.30	NAVD 1988	290	Apr-55	*NA*	272.57	6/21/96	287	?	NP	240	NA	55	381.3	?	NP	428	NA	613	?	NP	47	NA	185	55	X		NG, N			2	
E33-11	HT	573901	137636	*620.27* *	2.6	617.67	NGVD 29-2	230	Feb-54	*NA*			226.5	?	NP	195	NA	14	391.2	?	NP	423	NA	604	?	NP	32	NA	181	14	X		N, D	5-230		2	
E33-12	HT	573781	137633	626.79	2.4	621.00	NAVD 1988	415	Sep-53	305-385	222.63	8/10/98	232	?	NP	185	NA	22	389.0	?	NP	436	NA	599	?	NP	47	NA	163	22	X		N, D	5-415		2	Well completed in Rattlesnake Ridge Interbed
E33-13	HT	573707	137585	631.72	2.47	625.90	NAVD 1988	235	Oct-53	*210-235*	228.10	7/17/99	NR	?	NP	185	NA	20	NR	?	NP	441	NA	606	?	NP	NA	NA	165	20	X		NG,N, D, T	5-235		3	
E33-14	HT	573986	137567	625.41	2.5	622.91	NAVD 1988	230	Dec-53	*212-227*	222.46	6/30/99	228	?	NP	166	NA	20	394.9	?	NP	457	NA	603	?	NP	62	NA	146	20	X					2	
E33-15	HT	573810	137541	630.63	2.51	628.12	NAVD 1988	251	Feb-53	*222-237*	227.38	2/3/99	238.5	?	NP	170	NA	?	389.6	?	NP	458	NA	?	?	NP	69	NA	?	?	X		N, D	0-251		1	Driller's log maybe bad
E33-16	HT	573792	137465	642.07	0.5	641.57	NAVD 1988	252	Jan-53	*231-246*	239.04	2/3/99	246.5	229	203	NA	NP	24	395.1	413	439	NA	0	618	17.5	26.0	NA	NP	179	24	X		NG, N, D	0-258		3	
E33-17	HT	573879	137467	635.05	1.75	633.30	NAVD 1988	244	Oct-53	*220-244*	231.98	5/3/99	242.5	205	200	NA	NP	20	390.8	428	433	NA	205	613	37.5	5.0	NA	NP	180	20	X		N, D, T	5-240		2	
E33-18	HT	573779	137386	655.22	2.52	652.70	NAVD 1988	278	Feb-50	*240-260*	252.37	5/4/99	258	245	210	NA	NP	65	394.7	408	443	NA	245	607	13.0	35.0	NA	NP	164	45	X		NG,N, D, T	0-278		3	
E33-19	HT	573848	137423	653.98	2	648.59	NAVD 1988	252	Jun-56	*217-248*	235.45	7/14/74	249	220	205	NA	NP	22	399.6	429	444	NA	220	627	29.0	15.0	NA	NP	183	22	X		N, D	5-250		2	
E33-20	HT	573848	137398	653.40	1.25	652.15	NAVD 1988	254	Jul-56	*234-254*	250.38	5/3/99	254	226	209	NA	NP	36	398.2	426	443	NA	226	616	28.0	17.0	NA	NP	173	36	X		NG, N, D	5-250		3	
E33-21	HT	573475	137293	671.72	4.6	663.70	NAVD 1988	282	Apr-57	*235-275*	268.62	5/6/99	279	?	NP	220	NA	44	384.7	?	NP	444	NA	620	?	NP	59	NA	176	44	X		N, D	80-260		2	
E33-24	DB/HT	573494	137579	641.32	2.0	639.32	NAVD 1988	256.0	May-67	*219-241*			245	?	NP	180	NA	30	394.3	?	NP	459	NA	609	?	NP	65	NA	150	30	X					1	DB=0-20', 30-200'; HT=20-30', 200-256'; hole plugged and abandoned
E33-25	DB/HT	573365	137682	634.30	3.17	631.13	NAVD 1988	240	Feb-69	*199-233*	231.25	12/4/98	235	?	NP	140	NA	25	396.1	?	NP	491	NA	606	?	NP	95	NA	115	25	X		N, D	5-190		2	HT=0-25', 150-240'; DB=25-150'
E33-26	HT/DB	573333	137681	636.10	2.43	630.40	NAVD 1988	240	Mar-69	*NA*	234.20	5/4/99	239	?	NP	140	NA	30	391.4	?	NP	490	NA	600	?	NP	99	NA	110	30	X		N, D	5-240		2	
E33-27	HT	573668	137338	659.71	0.3	655.90	NAVD 1988	255	Jul-70	*NA*			NR	?	NP	NA	?	44	NR	?	NP	NA	?	612	?	NP	NA	?	?	44	X		NG, N, D			1	
E33-31	DB/HT	573525	137492	650.77	3.06	647.71	NAVD 1988	256	Sep-89	235-256	247.91	6/2/99	255.6	205	202	NA	NP	50	392.1	443	446	NA	205	598	50.6	3.0	NA	NP	152	50		X	NG		10-205	5	DB=0-210'; HT=210-255'
E33-32	DB/HT	573525	137354	663.33	3.09	657.20	NAVD 1988	270	Sep-89	246-267	260.56	6/2/99	269.0	230	223	NA	NP	30	388.2	427	434	NA	230	627	39.0	7.0	NA	NP	193	30		X	NG		5-245	5	DB=0-250'; HT=250-270'
E33-33	DB/HT	574080	137302	643.73	2.99	640.74	NAVD 1988	252	Aug-89	227-248	240.58	2/1/99	252.0	211	206	NA	NP	37	388.7	430	435	NA	211	604	41.0	5.0	NA	NP	169	37		X	NG		5-205	5	DB=0-216'; HT=216-252'

Table 2-1. Summary of Available Data for Boreholes Located Within 300 m (1,000 ft) of the B-BX-BY WMA. (2 sheets)

		State NAD83											Depth (ft. below ground surface)							Elevations (ft AMSL)						Thickness (ft)						Characterization Data						
Boring No.	Drill Method	Easting (m)	North-ing (m)	TOC (ft)	Stick-up (ft)	Surf. Elev. (ft)	Well Survey	Total Depth (ft)	Completion Date	Open Interval (ft bgs)	Depth to Water (ft)	Date of WL Measure-ment	TOB	Top Hf/PPu (?) Gravel	Top of Hf/PPu (?) Silt	Top of H3/PPU (undif.)	Top H3	Top H2	TOB	Top Hf/PPu (?) Gravel	Top Hf/PPu (?) Silt	Top H3/PPU (undif.)	Top H3	Top H2	Hf/PPu (?) Gravel	Hf/ PPu (?) Silt	H3/PPU (undif.)	H3	H2	H1	Drillers Log	Geologists Log	Geophy. Logs	Grain Size/ $CaCO_3$ (depth interval [ft.])	Moisture (depth interval [ft.])	Quality Ranking	Comments
E33-36	DB/HT	574069	137240	650.21	3	643.85	NAVD 1988	264	Apr-90	234-255	248.79	5/5/99	263.8	?	NP	209	NA	30	380.1	?	NP	435	NA	614	?	NP	55	NA	179	30		X				3	DB=0-210'; HT=210-264'; Water level abnormal (consistently low)
E33-38	DB/HT	573591	137595	635.27	2	633.27	NAVD 1988	239.6	Feb-91	219-240	231.48	5/4/99	238.0	190	189	NA	NP	13	395.3	443	444	NA	190	573	48.0	1.0	NA	NP	129	60		X	NG			4	DB=0-228, HT=228-240; CERCLA well, Lindsey log
E33-39	DB/HT	573844	137638	626.66	2.9	623.76	NAVD 1988	230.1	Feb-91	208-229	223.99	5/4/99	229.0	?	NP	175	NA	30	394.8	?	NP	449	NA	594	?	NP	54	NA	145	30		X	NG			4	DB=0-228, HT=228-230; CERCLA well, Lindsey log
E33-40	DB/SS/ HT	573546	137723	627.92	3.32	621.00	NAVD 1988	318	Apr-91	294-305	NA		228.0	?	NP	196	NA	49	393.0	?	NP	425	NA	572	?	NP	32	NA	147	49		X				3	Well completed at base of Elephant Mtn flow; hole bottoms in Rattlesnake Ridge Interbed; DB=0--219'; HT=219-305'
E33-41	DB	573707	137370	658.25	3.42	651.40	NAVD 1988	263	Mar-91	244-261	255.39	7/6/99	262.7	242	218	NA	NP	35	388.7	409	433	NA	242	616	20.7	24.0	NA	NP	183	35		X	NG			4	
E33-42	DB	573521	137424	657.58	3.42	654.16	NAVD 1988	260	Nov-91	239-260	254.73	7/6/99	260	?	NP	238	NA	28	394.2	?	NP	416	NA	626	?	NP	22	NA	210	28		X	NG		0-220	5	Lindsey log
E33-43	DB/HT	573523	137325	665.97	3.5	662.47	NAVD 1988	273.7	Nov-91	250-271	247.42	7/2/99	NR	225	210	NA	NP	45	NR	437	440	NA	225	617	NA	3.0	NA	NP	177	45		X	NG		10-270	5	Lindsey log; DB=0-210'; HT=210-255,
E33-44	DB/HT			645.70	2.66	643.00	NAVD 1988	255	Sep-98	238-253	239.60	9/26/98	247.4	210	207	NA	NP	23	395.6	433	438	NA	210	620	37.4	5.0	NA	NP	182	23		X	NG, N			5	DB=0-245'; HT=245-255'; CaCO3=5-245'

HT = Hard Tool
DB = Drive Barrel
SS = Split Spoon

Older survey

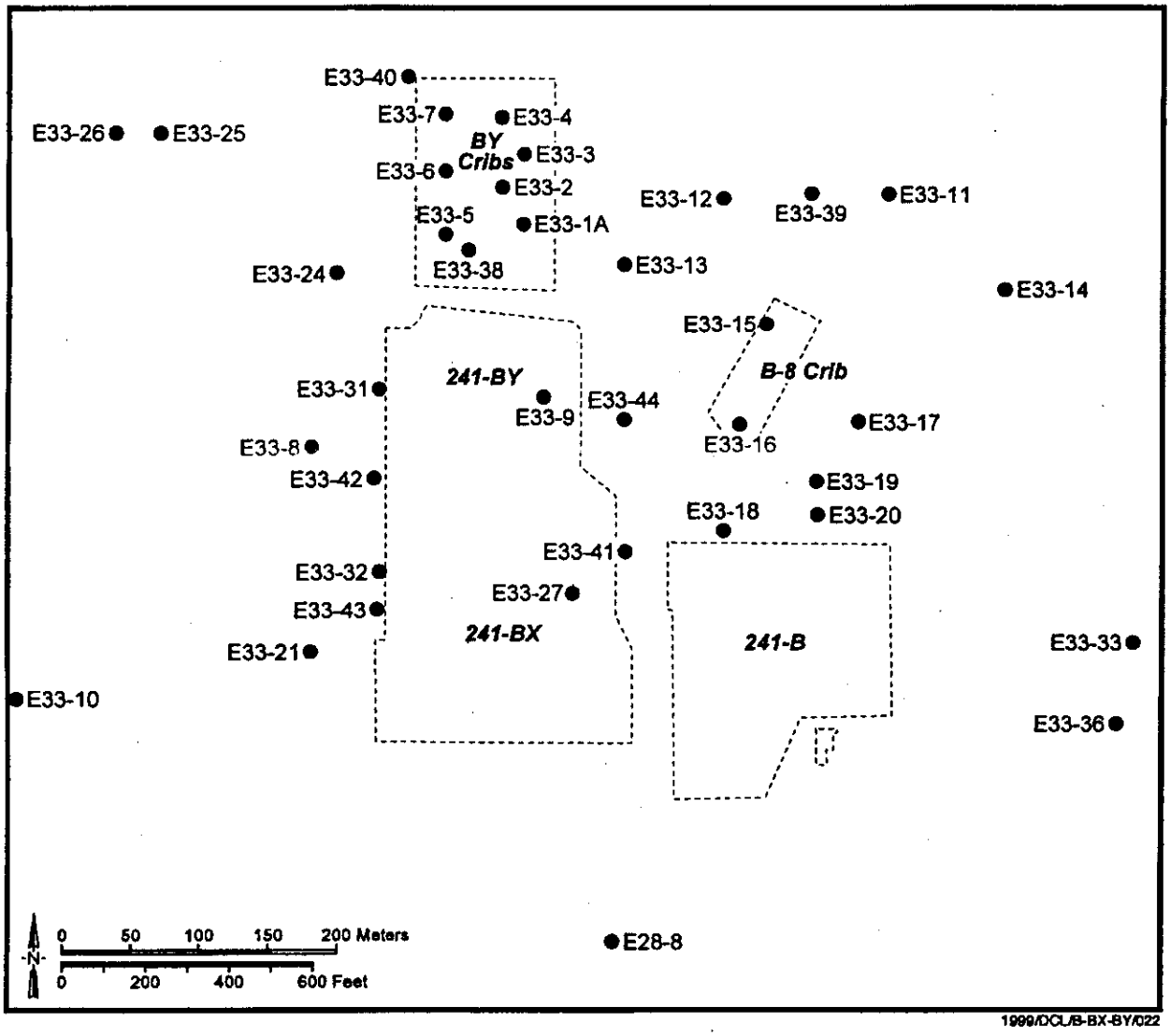
Perforated open interval

NR= Not Reached
NA = Not Applicable
NP= Not Present

NG=Natural (gross) gamma
N=neutron (moisture)
D=density
T=temperature

1 = lowest quality
5 = highest quality

Figure 2-2. Borehole Location Map.



2.2.1 Geomorphology

The B-BX-BY WMA lies along the northern flank of the Cold Creek bar, a large compound flood bar formed during Pleistocene ice-age floods (Figure 2-3). The upper surface of the bar in the 200 East Area forms a broad plain at about the 210 m (700-ft) elevation. The bar extends westward for several kilometers (miles); the northern boundary of the bar is defined by a series of northwest-southeast- trending flood channels (DOE 1988). This WMA is located on the grade that slopes gently (about 0.085 m/m [0.026 ft/ft]) to the northeast from the Cold Creek bar into the uppermost flood channel (see Figure 2-3).

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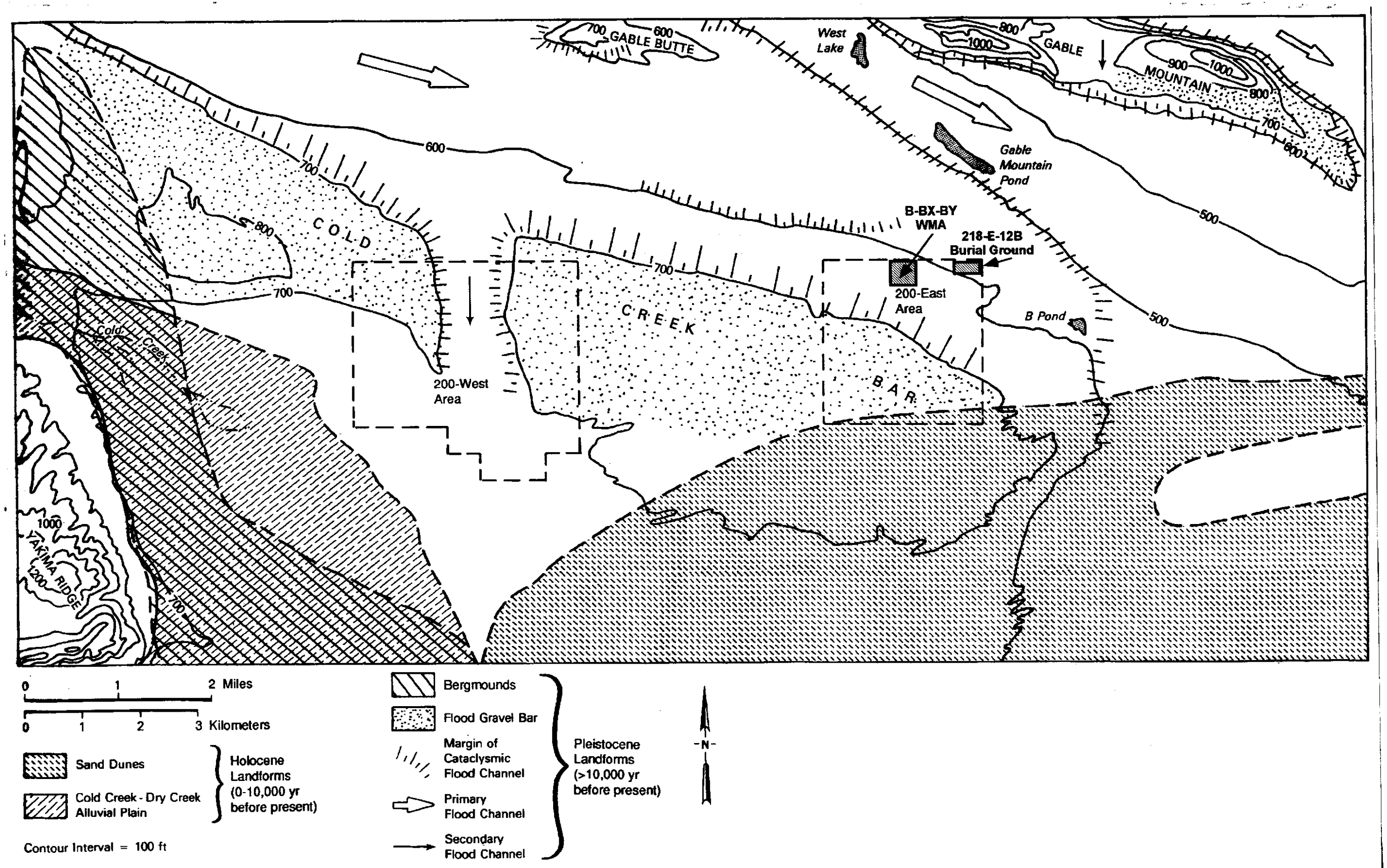
Figure 2-3. Geomorphic Map.



Reverse of foldout

2.2.2 General Stratigraphy

The six stratigraphic units recognized in this WMA are shown in Figure 2-4. They consist of the following:

- Recent backfill material
- Hanford formation - upper gravel sequence (H1 unit)
- Hanford formation - sand sequence (H2 unit)
- Hanford formation - lower gravel sequence (H3 unit)
- Hanford formation/Plio-Pleistocene unit (?)
- Columbia River Basalt Group.

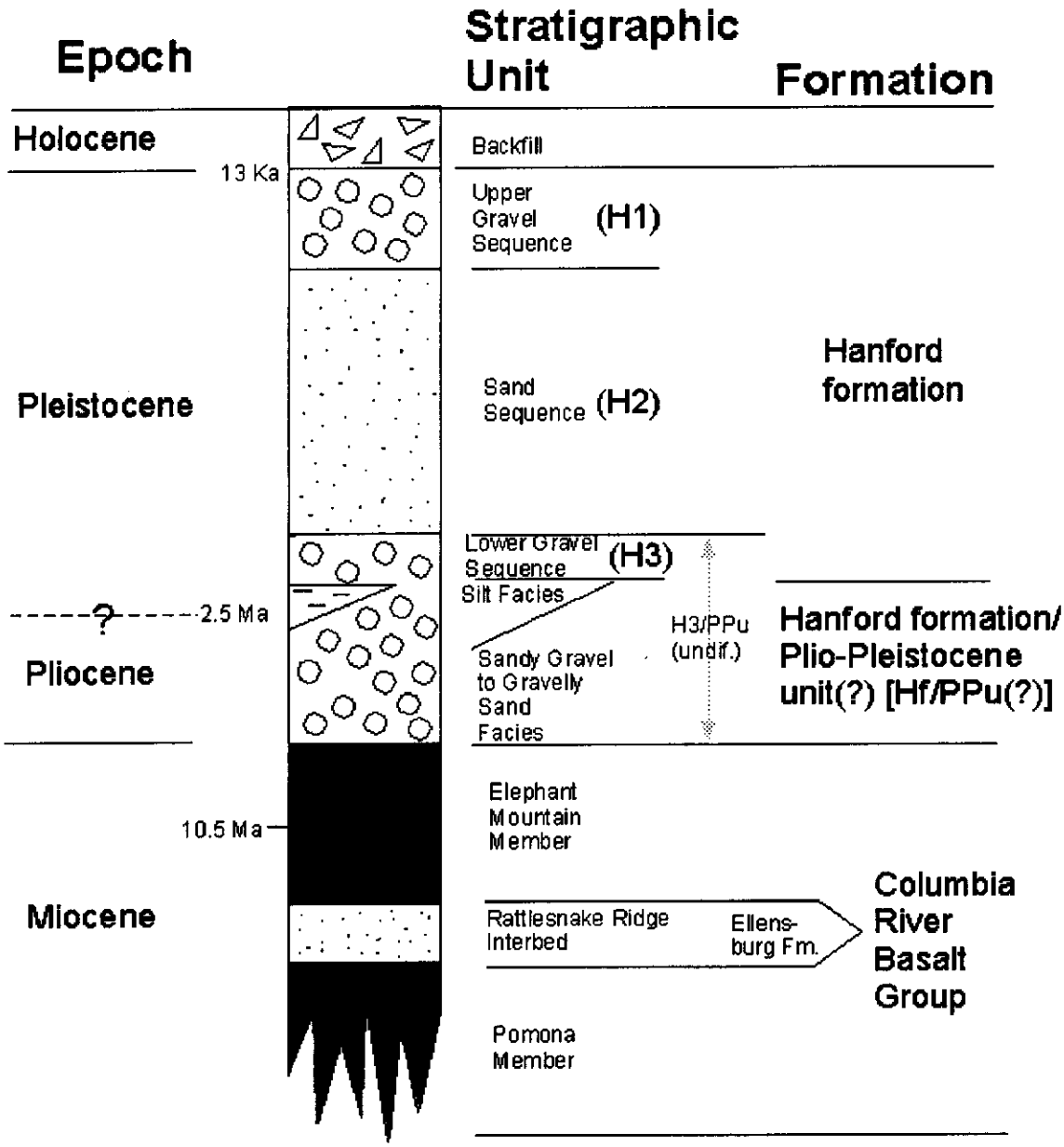
The tank farms that constitute the B-BX-BY WMA (see Figure 2-2) were constructed in the near-surface sediments that overlie the Columbia River Basalt Group (i.e., bedrock) on the northern limb of the Cold Creek syncline. Suprabasalt sediments in the vicinity of this WMA are unconsolidated and include possible facies of the Plio-Pleistocene unit as well as sand, gravel, and lesser amounts of silt-dominated deposits from Pleistocene cataclysmic floods, collectively referred to as the Hanford formation (see Figure 2-4). The fluvial-lacustrine Ringold Formation, which overlies basalt over most of the Hanford Site, is not present beneath in the WMA, having been completely eroded away since Ringold time. Plio-Pleistocene-age fluvial, and perhaps some eolian, deposits appear to lie between the Columbia River Basalt Group and the overlying cataclysmic ice-age flood deposits (i.e., the Hanford formation). In the vicinity of this WMA, the Hanford formation is subdivided into an upper and lower gravel sequence (H1 and H3 units, respectively) and an intervening sequence composed predominantly of sand (H2 unit).

The vadose zone beneath the WMA is as much as 83 m (273 ft) thick and consists of the Pleistocene-aged Hanford formation and the Hanford formation/Plio-Pleistocene unit (?) [Hf/PPu(?)]. The unconfined aquifer beneath the WMA is generally only a few meters (feet) thick and, in places, the top of basalt extends above the water table (see Section 2.4.2). The saturated zone lies within the H3/Plio-Pleistocene units (undifferentiated).

2.2.3 Methodology

2.2.3.1 Data Sources. Borehole data, consisting of driller's logs, geologist's logs, archived samples, and geophysical logs, along with limited characterization data (grain-size distribution, calcium carbonate content, and moisture content), are the principal data sets used to interpret the subsurface at this WMA. In addition, numerous reports describing the geology of the area (e.g., Tallman et al. 1979, DOE 1988, Last et al. 1989, and Lindsey 1991 and 1995) create the foundation from which the model has evolved. The types of data available for boreholes within 300 m (1,000 ft) of the WMA are summarized in Table 2-1.

Figure 2-4. Stratigraphy in the Vicinity of the B-BX-BY Waste Management Area.



Initially, well-site geologist's logs or driller's logs were examined and compared to geophysical logs from the boreholes. The quality of drilling logs varies because many wells and boreholes were drilled without a geologist present at the site. This is generally true for all boreholes drilled before the mid-1980s. Until then, drillers collected sediment samples every 1.5 m (5 ft) and included general descriptions of the formation materials and problems encountered on drilling-summary forms. Most of the archived sediment samples from the pre-1980 wells were subsequently analyzed in the laboratory for grain-size distribution and calcium carbonate content; these results reside in an old database called ROCSAN, which is no longer operational. For this study, grain-size distribution and calcium carbonate content were manually reentered into EXCEL spreadsheets from a hard copy of the ROCSAN database printout.

The quality of the grain-size distribution data depends largely on the drill method used. Intervals drilled with a hard tool tend to produce more fines because of the pulverizing action of the hard-tool bit. An alternative method is the drive-barrel, which better preserves the original grain-size distribution, but still can result in some pulverization. A third method of collecting sediment samples is the split-spoon method; in which a small-diameter core barrel permits collection and preservation of sediment core within a metal or plastic sleeve. The split-spoon method provides the best quality sample for geologic description and laboratory analysis. Unlike grain-size distribution data, the quality of the calcium carbonate data are believed to be representative, irrespective of drill method because the drill method does not affect the bulk chemistry of the sample.

Beginning in the mid-1980s, about the time geologists assumed responsibility for lithologic descriptions at drill sites, samples no longer were routinely analyzed in the laboratory. Therefore, quantitative grain-size distribution and calcium carbonate data are not available for boreholes drilled since the mid-1980s; however, these parameters have been provided qualitatively in geologists logs.

Geophysical logs (e.g., gross-gamma ray), available for most boreholes, vary greatly in quality, but are useful for identifying some of the stratigraphic contacts. Geophysical logs sometimes show lithologic differences because they contain different amounts of natural gamma-ray emitters (most commonly ^{40}K). The proportion of ^{40}K generally increases with decreasing grain size; therefore, clay and silt generally emit more natural gamma rays than gravel and sand. Sample retrieval sometimes is difficult and often does not permit a determination of the exact depth of contacts. The gross-gamma log more accurately determines depths of fine-grained layers, especially those a meter (foot) or more thick. However, thin clay and/or silt layers often still go undetected on gross gamma logs.

Another data source useful for interpreting the lithology is moisture content. Within the vadose zone, moisture content generally increases along interfaces between materials with highly contrasting grain size. Using a moisture log in combination with a gross-gamma log aids in interpreting the lithology.

2.2.3.2 Development of Geohydrologic Model. The conceptual geohydrologic model presented here is developed from available driller's logs, geologist's logs, geophysical logs, archived sediment samples, and field and laboratory characterization data. All available data for each borehole within 300 m (1,000 ft) of the WMA were compiled and summarized onto a separate borehole summary sheet. Boreholes in the vicinity of the WMA are ranked in Table 2-1 according to the quality of data and degree of uncertainty in the interpretation of the borehole

geology. Each borehole is ranked from 1 to 5, with 5 having the highest confidence and least uncertainty in the geologic interpretation. Those ranked 1 (least confidence and highest uncertainty) are boreholes with only a driller's log available. In contrast, those ranked 5 (highest confidence and least uncertainty) have geologist's logs accompanied by gross-gamma and moisture logs, as well as grain-size, calcium carbonate content, and other characterization data.

The model was built using a series of investigative steps designed to honor the data and give preference to the higher ranked boreholes. First, the main stratigraphic units and contacts were identified in boreholes ranked 4 or 5. This was done by comparing available data and picking depths to major lithologic contacts (i.e., units with approximately uniform grain size). Elevations and thicknesses of the major stratigraphic contacts then were calculated from the depths. Next, the same procedure was performed on lower ranked boreholes. One of the last steps was to plot the elevations and thicknesses of these major units onto structure-contour and isopach maps, respectively, to determine if the contacts are realistic and make sense geologically. If the contacts are chosen correctly, the data should plot as relatively smooth surfaces, transitioning from one borehole to another. Isolated, large, steep-gradient "bulls eyes" on contour maps indicate the contact may be miscalculated. In these cases, boreholes would be reevaluated and the contact adjusted as necessary.

The next step in building a geohydrologic model of the subsurface was to construct scaled cross sections linking boreholes together. Five cross sections (shown in Figure 2-5) are detailed in Appendix B (Figures B-1 to B-5). Ideally, cross sections should trend at approximate right angles to one another to obtain a representative, three-dimensional view of the subsurface. Once the investigator was confident that contacts were correctly chosen on contour maps and cross sections, the final step was to construct a fence diagram that links the cross sections into one three-dimensional diagram (Figure B-6). See Figure 2-6 for a location map of the three-dimensional fence diagram that encompasses the B-BX-BY WMA.

2.2.4 Uncertainty

Sources of uncertainty for contact locations between stratigraphic units in boreholes and correlations between boreholes include the following:

- **Borehole Related**. These include the drilling method, the source and quality of the borehole and geophysical logs, and borehole spacing.
- **Sampling Related**. These include the method of drilling and sampling, sampling frequency, and bias induced by the sampling techniques.
- **Geology Related**. These include the three-dimensional shape of the sedimentary features; lateral facies changes in relative proportion of sand, silt, and gravel; and bed-form properties of the sediment layers.

Figure 2-5. Cross Section Location Map.

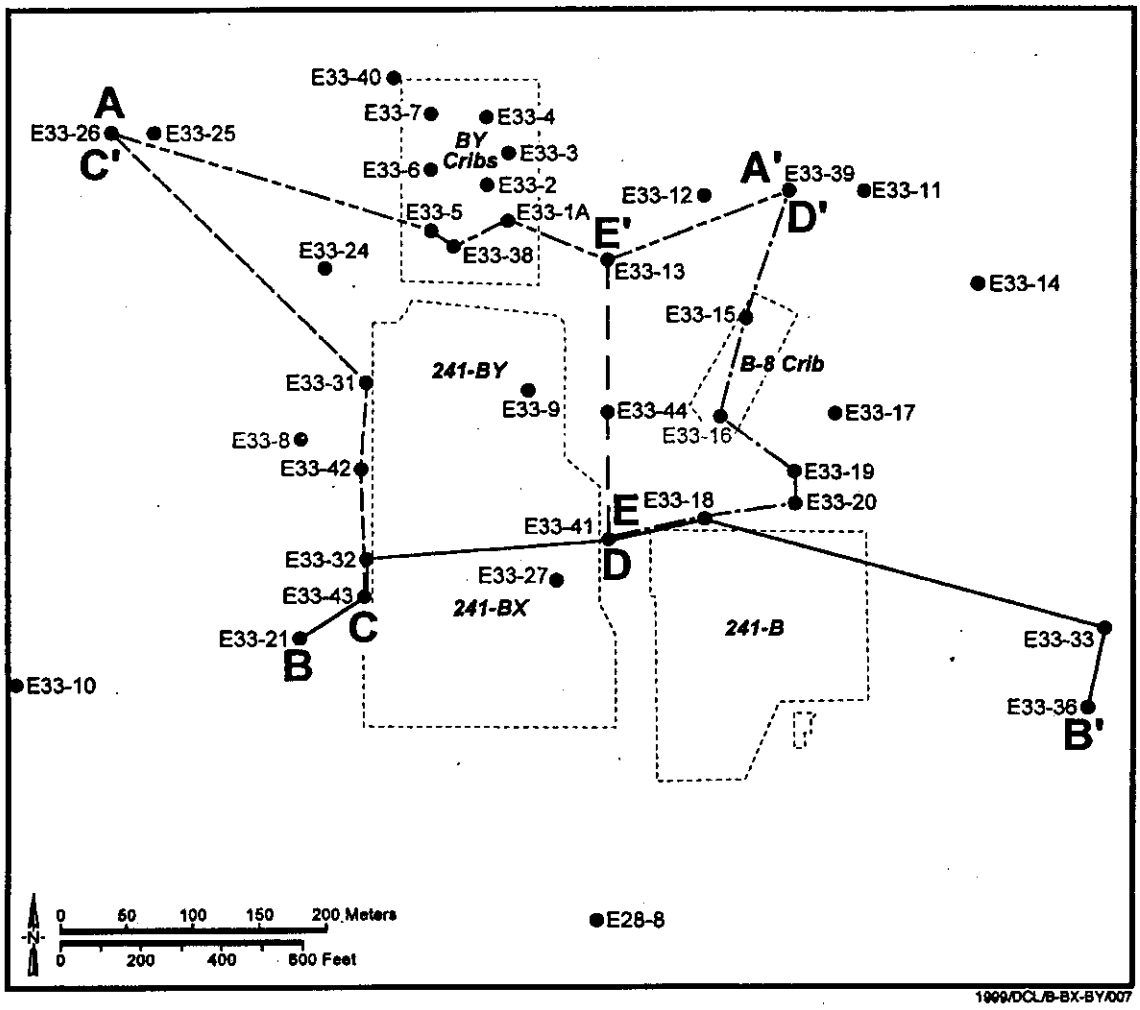
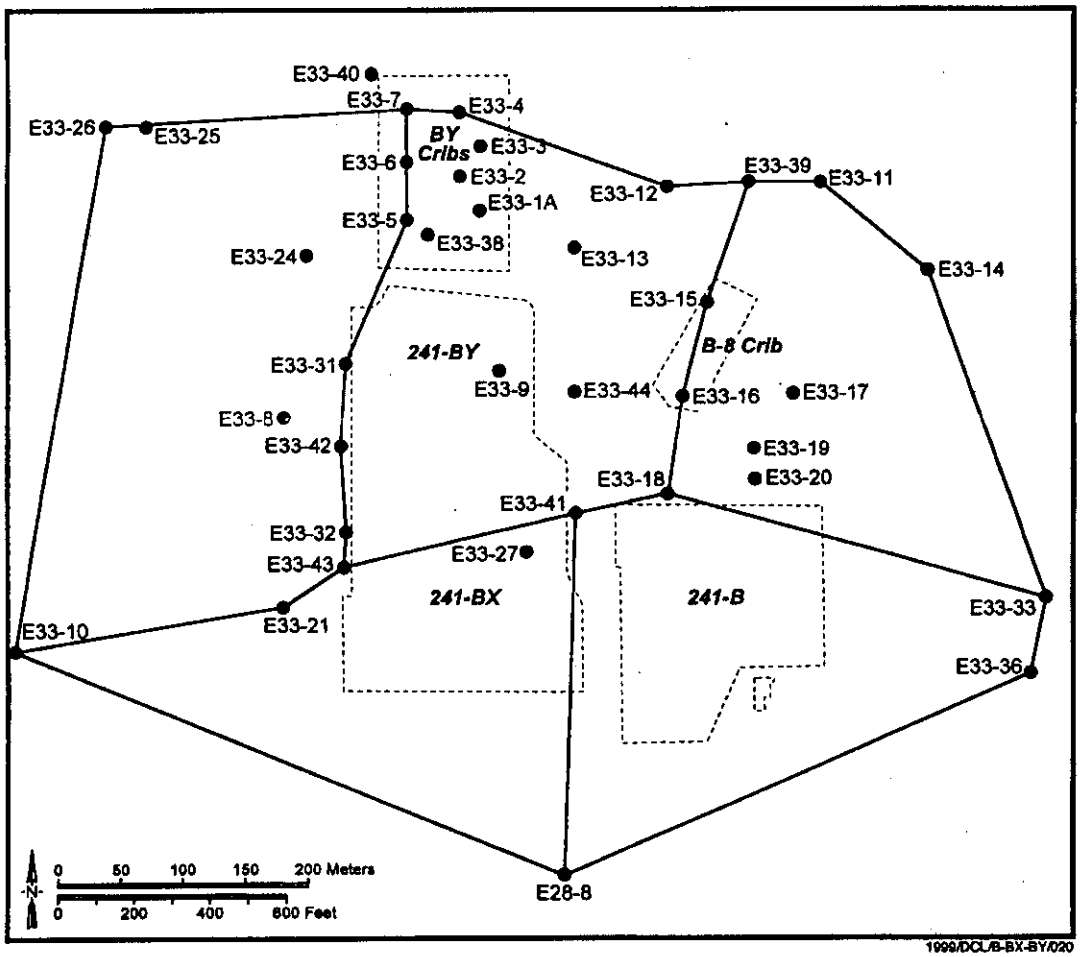


Figure 2-6. Fence Diagram Location Map.



2.2.4.1 Borehole-Related Uncertainty. All boreholes in the vicinity of the B-BX-BY WMA were drilled using cable-tool percussion techniques. Cable-tool drilling has been the standard technique from earliest drilling at the Hanford Site. Drilling advances by use of a drive barrel or hard tool and driven temporary casing. While the cable-tool method has proved successful, in the loose, unconsolidated, gravel-dominated facies of the Hanford formation, it has the following disadvantages:

- Sample size is limited.
- Water often must be added to give the sample cohesive strength to keep it in the drive barrel, which is especially true of the loose, dry sand of the Hanford formation, which lacks cohesive strength inside the drive barrel.
- Sample depth is difficult to control.

2.2.4.2 Sampling-Related Uncertainty. The type and quantity of characterization data collected vary substantially between boreholes, which adds uncertainty and complicates stratigraphic correlations based on different data sets or data quality. Sample collection in the

unconsolidated vadose-zone formations (i.e., Hanford formation) often is challenging because the samples are typically dry and are not easily retained in the drive barrel.

Because drillers had widely different experience and backgrounds and lacked training in geologic descriptions, the quality of their logs is highly variable and inconsistent. The quality and consistency of borehole logs improved significantly in the 1980s, when the responsibility for geologic logging and sampling of the boreholes shifted to geologists.

The quality of the geophysical logging (i.e., gross-gamma log) also varied over the years. Earlier logs often were not calibrated to a standard and/or were run at rapid rates, which adversely affected data quality. However, the older logs are still useful for qualitative comparison and for identifying lithologic contacts.

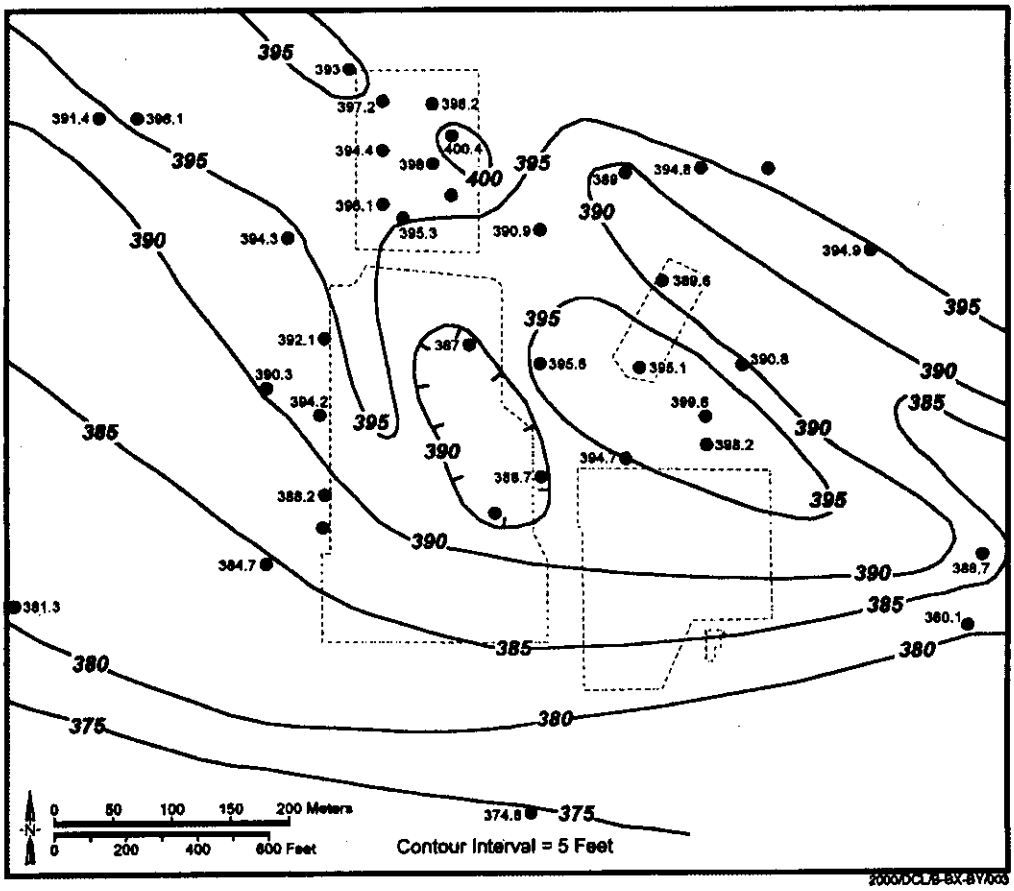
2.2.4.3 Geologic-Related Uncertainty. In addition to the uncertainty in borehole data, uncertainty also occurs in the geometric shape and distributions of the sediment bodies. Because of the scale and dynamic nature of the cataclysmic flooding that produced the Hanford formation, very few analogs are available to compare the geologic model at the B-BX-BY WMA to a field locality. Surface excavations, such trench 94 in the 218-E-12B Burial Ground, near this WMA provide valuable information on the types and scales of natural heterogeneity within the Hanford formation. This information cannot be determined from borehole logs alone.

2.2.5 Columbia River Basalt Group

The surface of the Columbia River Basalt Group forms the bedrock base of the unconfined aquifer under the B-BX-BY WMA. The Elephant Mountain Member of the Saddle Mountains Basalt is the youngest flow and ranges from 70 m to 100 m (230 to 320 ft) below the land surface. The top of the basalt dips southwest toward the axis of the Cold Creek syncline (Figure 2-7). Up to 8 m (25 ft) of topographic relief exist on the basalt surface. Based on the topography on the top of basalt (Figure 2-7), some of this relief appears caused by post-basalt channeling into the basalt, probably during late Pliocene time. The predominant northwest-southeast structural trends on the top of the basalt are consistent with the trend of other eroded and/or deformed basalt highs in the region. In general, lavas of the Saddle Mountains Basalt and the overlying suprabasalt sediments thicken to the south toward the axis of the Cold Creek syncline.

The Elephant Mountain Member is medium- to fine-grained tholeiitic basalt with abundant microphenocrysts of plagioclase (DOE 1988). The Elephant Mountain Member has been dated by the potassium/argon method to have been formed approximately 10.5 million years ago (McKee et al. 1977). It consists of two flows beneath the 200 East Area. Because the water table is near the top of the basalt bedrock, most boreholes beneath the WMA were drilled until they intersected basalt. Two boreholes penetrated the Elephant Mountain Member: 299-E33-40 terminated within the first interbed (Rattlesnake Ridge interbed of the Ellensburg Formation) and 299-E33-12 advanced through the first interbed into the underlying Pomona Member of the Saddle Mountains Basalt.

Figure 2-7. Top of Basalt Surface.



2.2.6 Ringold Formation

The fluvial-lacustrine Ringold Formation, which overlies basalt over most of the central Pasco Basin, is not present beneath the WMA. The Ringold Formation was present at one time and probably filled the basin with sediments to at least 724 m (900 ft) in elevation (Lindsey 1996)during the late-Miocene to Pliocene time (10.5 to 3.4 Ma). However, in the vicinity of the WMA, the Ringold Formation since has been effectively removed by fluvial down-cutting of the ancestral Columbia River, cataclysmic ice-age flooding, or both.

2.2.7 Hanford Formation/Plio-Pleistocene Unit(?)

A unit of questionable origin locally overlies basalt within the B-BX-BY WMA. This unit may be equivalent or partially equivalent to the Plio-Pleistocene unit or it may represent the earliest ice-age flood deposits overlain by a locally thick sequence of fine-grained non-flood deposits. This unit is referred to as the Hanford formation/Plio-Pleistocene unit (?)[Hf/PPu(?)] (Figure 2-4).

Since Ringold time, (approximately 3.4 million years ago, base level within the Pasco Basin dropped approximately 600 ft, leading to incision and erosion of the preexisting Ringold Formation deposits by the ancestral Columbia River system. Once the new base level was

established, erosion stopped allowing local deposition and partial backfilling of the eroded landscape by fluvial deposits toward the center of the basin and eolian/flood-plain deposits distally, while paleosols formed in low-relief upland and interfluvial areas. Beginning about 2 million years ago, ice-age floods from ice-dammed lakes north and east of the Columbia Plateau inundated the region. In some places within the Pasco Basin, the ice-age floodwaters scoured further into basalt bedrock, while in other places flood deposits blanketed older Ringold and/or post-Ringold deposits.

Deposits in the Pasco Basin that postdate the Ringold Formation and predate the ice-age floods are referred to as the Plio-Pleistocene unit (DOE 1988, Lindsey et al. 1994). Several facies of the Plio-Pleistocene unit include the well-defined calcic paleosol (caliche) facies reported from the 200 West Area (DOE 1988, Slate 1996), a sidestream alluvial facies (Bjornstad 1984, DOE 1988, Slate 1996), and, recently, an eolian facies (Slate 1996), which originally was described as a separate unit (i.e., early "Palouse" soil). A mainstream facies of the Plio-Pleistocene unit also is reported across the basin associated with deposition by the ancestral Yakima, Snake, and Columbia Rivers (Lindsey et al. 1994).

Post-Ringold age late-Pliocene to early-Pleistocene deposits 2.0 to 3.4 million years before present or less) may be present beneath the B-BX-BY WMA. Two facies of the Hf/PPu(?) represented beneath the B-BX-BY WMA are: eolian/overbank silt and sandy gravel to gravelly sand of uncertain origin.

2.2.7.1 Silt Facies. A locally thick layer of silt lies several tens of meters (feet) above the top of the basalt. Based on drill logs and an examination of drill cuttings, this unit consists of olive brown to olive gray well-sorted calcareous silt and/or fine sand. Both laminations and pedogenic structures (i.e., mottling, root traces, etc.) are present in the larger, intact pieces recovered with the drive barrel in some boreholes, while in other boreholes, the silt appears to be massive and void of any sedimentary or pedogenic structure. The silt layer is up to 10 m (35 ft) thick in well 299-E33-18 (see Figure B-7 in Appendix B). Cataclysmic flood deposits of the Hanford formation typically do not contain fine-grained beds more than a meter (3 feet) thick; therefore this silt layer is believed to be a pre-ice-age flood deposit or, possibly, an inter-ice-age flood deposit, consisting of either overbank-flood-plain alluvium from the ancestral Columbia River or eolian loess. The silt layer could be equivalent or partially equivalent to the early "Palouse" soil, an eolian unit reported beneath the 200-West Area (Tallman et al. 1979, DOE 1988), and recently included with the Plio-Pleistocene unit (Lindsey et al. 1994, Slate 1996).

Alternatively, the thick silt layer at the top of the Hf/PPu(?) may represent an interglacial deposit of alluvium and/or loess deposited between major advances of the ice sheet and associated Missoula floods during the early Pleistocene. Some evidence to support this interpretation is the composition (50 to 70 percent basalt) of the sandy gravels underling the silt layer, which appears to be identical to sandy gravels of known origin (flood gravels of the Hanford formation) above the silt layer. If the sandy gravel to gravelly sand facies below the silt layer were pre-ice-age flood deposits (i.e., alluvial facies of the Plio-Pleistocene unit) they would be expected to contain a greater proportion of felsic to mafic constituents (Lindsey et al. 1994), especially considering the close proximity of the B-BX-BY WMA to the ancestral Columbia River. The exact origin and age of these gravels beneath the silt layer is inconclusive at this time and awaits further investigation.

The silt layer is present only locally in an area centered over the northwest portion of the B Tank Farm (see Figure B-7); elsewhere, it was either subsequently eroded or not deposited. The

top of the Hf/PPu(?) silt layer appears to dip slightly toward the northeast (see Figure B-8). Where the silt layer is missing, which is over most of the WMA, the Hf/PPu(?) cannot be distinguished from the overlying Hanford formation.

2.2.7.2 Sandy Gravel to Gravelly Sand Facies. The loose, unconsolidated nature of the sandy gravels to gravelly sands suggests the sediments below the Hf/PPu(?) silt layer are post-Ringold in age. However, as mentioned above, sands and gravels beneath the silt layer are compositionally similar to the basaltic sands and gravels above the silt layer, suggesting this facies represents either flood gravels (Hanford formation) or pre-ice-age-flood plane alluvium with perhaps a significant sidestream component (mixed mainstream and sidestream facies of the Plio-Pleistocene unit).

A single hydraulic conductivity value, reported for sandy gravel within the Hf/PPu(?) in well 299-E33-33 (Caggiano 1993), is 98 m/day (320 ft/day). This value is between those normally reported for the Hanford formation (450 m/day to 27,000 m/day [1,500 to 90,000 ft/day]) and the Ringold Formation gravel facies (3 m/day to 70 m/day [9 to 230 ft/day]) (Bjornstad 1990), suggesting this unit may be more compacted and/or consolidated than the overlying flood gravels of the Hanford formation

The upper surface of the Hf/PPu(?) sandy gravel to gravelly sand facies shows approximately 10 m (30 ft) of relief. A depression, centered over the northwestern corner of the B Tank Farm, exists at the top of this unit. The depression appears to be filled with the overlying Hf/PPu(?) silt layer (see Figures B-7 and B-8). The thickness of the gravel ranges from 5 m to 15 m (20 to 50 ft) (see Figure B-9). The unit is both thinnest and structurally low near the same point, suggesting that the top of the Hf/PPu(?) gravel was eroded before the depression was backfilled with Hf/PPu(?) silt facies (Figure B-10).

Gravel facies of the Hf/PPu(?) within the B-BX-BY Tank Farms area can only be differentiated where the intervening, massive layer of eolian and/or overbank silt is present. Where the silt is absent, however, it is not possible, with existing borehole information, to distinguish between the Hf/PPu(?) and overlying Hanford formation flood deposits. It does not necessarily mean that deposits of Plio-Pleistocene age are absent, only that they cannot be differentiated. With improvements and advances in geophysical logging and aquifer characterization, perhaps the boundaries of this unit will become easier to identify.

Within the Hf/PPu(?) gravels, a distinctive sudden shift occurs in the $CaCO_3$ content from 0 percent in the lower part to 2 to 3 percent in the upper part. This marker horizon is apparent only in a string of wells, trending east-west, located in the northern portion of the WMA (Figure B-11). The cause and significance of this marker horizon are not clear, but may represent a transition in climate to more arid conditions, which are known to have occurred during Pliocene to Pleistocene times.

2.2.8 Hanford Formation

The Hanford formation is the informal name given to all glaciofluvial deposits from cataclysmic ice-age floods. Sources for floodwaters included glacial Lake Missoula, pluvial Lake Bonneville, and ice-margin lakes that formed around the margins of the Columbia Plateau (Baker et al. 1991). Based on long-term, oxygen-isotope variations in deep-sea cores (Morrison

1991), at least 6 major glacial-interglacial cycles are recorded over the last 600,000 years. On average, interglacial conditions lasting about 50,000 years have been separated by major glacial advances, also averaging about 50,000 years. To date, ice-age flood deposits from only four of the major glacial events that occurred between 1 million and 13,000 years ago are identified within the Pasco Basin (Baker et al. 1991, Reidel and Fecht 1994). Evidence to support the other major glacial cycles in the Pasco Basin either are masked or have been destroyed by subsequent ice-age floods. The Hanford formation consists of mostly unconsolidated sediments that cover grain sizes from pebble to boulder gravel, fine- to coarse-grained sand, silty sand, and silt. The formation is further subdivided into gravel-, sand-, and silt-dominated facies, which transition into one another laterally with distance from the main, high-energy, flood currents. The Hanford formation is made up of the following facies.

- **Gravel-Dominated (Coarse-Grained) Facies**. This facies generally consists of coarse-grained basaltic sand and granule to boulder gravel. These deposits display an open framework texture, massive bedding, plane to low-angle bedding, and large-scale planar cross bedding in outcrop. Gravel-dominated beds sometimes grade upward into sand- and silt-dominated facies. Gravel clasts are predominantly basalt, with lesser amounts of Ringold Formation clasts, granite, quartzite, and gneiss (Lindsey et al. 1992). The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channelways.

- **Sand-Dominated (Transitional) Facies**. This facies consists of fine- to coarse-grained sand and granule gravel. The sands typically have a high-basalt content and are commonly referred to as black, gray, or "salt-and-pepper" sands. They may contain small pebbles, rip-up clasts, and pebble-gravel interbeds. They often grade upward into zones of silt-dominated facies less than 1 m (3-ft) thick. This facies commonly displays plane lamination and bedding and, less commonly, channel cut-and-fill sequences. The sand-dominated facies was deposited adjacent to main flood channelways during the waning stages of flooding. The facies is transitional between the gravel-dominated facies and the silt-dominated facies.

- **Silt-Dominated (Rythmite) Facies**. This facies consists of thin-bedded, plane-laminated, and ripple cross-laminated silt and fine- to coarse-grained sand. Beds are typically a few to several tens of centimeters (inches) thick and commonly display normally graded bedding (Lindsey et al. 1992). Sediments of this facies were deposited under slackwater conditions and in back-flooded areas (DOE 1988, Baker et al. 1991).

The sand and gravel fractions of the Hanford formation generally consist of about 50 percent basalt and 50 percent felsic material (Tallman et al. 1979). This mineral assemblage gives the Hanford formation the characteristic "salt and pepper" appearance often noted in driller's and geologist's logs. The felsic material is composed of primarily quartz and feldspar, with some samples containing more than 10 percent pyroxene, amphibole, chlorite, ilmenite, and magnetite.

The Hanford formation makes up the majority of the suprabasalt sedimentary sequence beneath the B-BX-BY WMA, ranging in thickness from 43 m to 73 m (140 to 240 ft). Based on lithologies observed at the WMA, the Hanford formation can be divided into three informal units (H1, H2, and H3). The H1 and H3 units consist of mostly coarse-grained gravel or sandy gravel;

the H2 unit is predominantly sand or gravelly sand, with occasional beds of sandy gravel. H1 and H3 belong to the gravel-dominated facies of the Hanford formation, associated with deposition within and along the main ice-age flood channelways. The sand-dominated H2 unit was deposited under less-energetic currents, perhaps farther away from the main channelway. The third facies of the Hanford formation, the silt-dominated facies, is occasionally present at the top of some beds, but it is a minor component in these overall higher energy flood deposits.

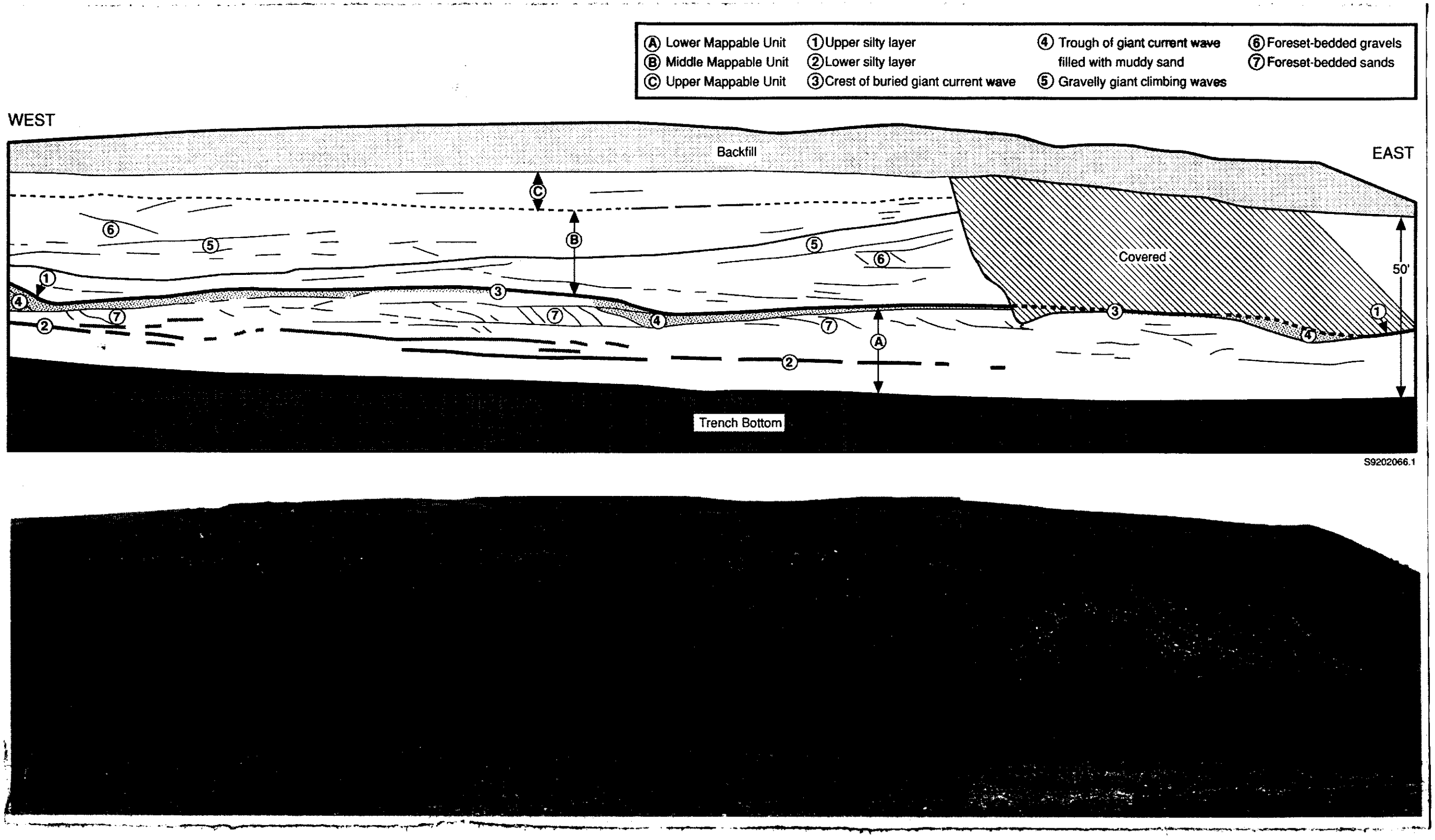
Because of the scale and dynamics of ice-age floods, the characteristics of the Hanford formation are unlike almost any other type of sedimentary deposit. For this reason, an accurate assessment of the Hanford formation cannot be realized from boreholes alone. Only through the study of outcrops can the actual stratigraphic relationships between ice-age flood deposits be evaluated accurately. Fortunately, an excellent exposure of the Hanford formation exists just to the east of the WMA on the sidewall of trench 94 in the 218-E-12B Burial Ground, which was excavated for the disposal of U.S. Navy nuclear submarine reactor cores (Rhoads et al. 1994).

Figure 2-8 is a composite photograph and facies analysis of a portion of trench 94. The walls of this large, 15 m (50-ft)-deep, open pit, photographed and surveyed soon after excavation, display a sequence of flood gravels, sands, and silts deposited during the last late-Pleistocene cataclysmic floods (Lewis et al. 1993). Within the excavation, the upper gravel sequence (H1 unit) and the uppermost portion of the sand sequence (H2 unit) appear to be represented. The complexity and heterogeneity inherent in these coarse-grained (i.e., high-energy) flood deposits are illustrated in the upper half of Figure 2-8. Of particular note is a series of six giant current ripples, buried 10 m (30 ft) below ground surface that developed near the top of the sand sequence (H2 unit). The ripples, which display an amplitude of 1.8 m (6 ft), are asymmetric and approximately 60 m (200 ft) apart. Current ripples of this magnitude are characteristic of cataclysmic ice-age floods (Baker 1978). Paleoflow indicators suggest the ripples were laid down by high-energy flood currents moving from west to east along the northern edge of the Cold Creek bar in a depositional environment similar to that of the B-BX-BY WMA. Two separate layers of lower permeability, fine sand and silt are present within the 15 m (50-ft) sequence and partially fill troughs between ripple crests. These finer grained layers thin to only a few centimeters (inches) over the ripple crests. Significantly, these fine-grained layers are continuous across the entire 140 m by 450 m (460- by 1,480-ft) excavation, even though the thickness varies considerably. Because these fine-grained layers have lower permeability and retain more moisture than the coarser grained layers, they may intercept water moving downward through the vadose zone.

2.2.8.1 Lower Gravel Sequence (H3 Unit). Within the B-BX-BY WMA the Hanford formation lower gravel sequence (H3 unit) locally overlies either basalt bedrock or the Hf/PPu(?). If the Hf/PPu(?) silt facies represents an inter-glacial nonflood deposit, the H3 unit may be stratigraphically equivalent to the Hf/PPu(?) sandy gravel to gravelly sand facies. The H3 lower gravel sequence is equivalent to the lower gravel sequence of the Hanford formation described in Last et al. (1989) and Lindsey et al. (1992), to the Hanford formation H3 sequence described in Lindsey et al. (1994), and to the Qfg (Quarternary flood gravels) deposits documented in Reidel and Fecht (1994).

The H3 unit was probably deposited within or adjacent to a high-energy, cataclysmic, ice-age, flood channel. The Hanford formation lower gravel sequence is described on borehole logs of cuttings and samples from near the B-BX-BY WMA as predominantly gravelly sand, with some gravel and sandy gravel. Based on observations of outcrop and intact core, the lower

Figure 2-8. Photograph and Facies Analysis of Portion of the 218-E-12-B Burial Ground.



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gravel sequence is interpreted to belonging to the gravel-dominated facies of the Hanford formation. Lenticular and discontinuous units of sand-dominated facies are sometimes interbedded with the gravel-dominated facies.

The H3 unit is not continuous beneath the B-BX-BY WMA; it generally is missing from the central portion of the waste site, where, in its place, lies the Hf/PPu(?). Where the Hf/PPu(?) silt layer is missing, the H3 and Hf/PPu(?) cannot be differentiated; these units are referred to collectively as the H3/Plio-Pleistocene unit (undifferentiated). A structure-contour map of the top of the Hanford formation lower gravel sequence (H3 unit) is shown in Appendix B, Figure B-12. The map shows approximately 20 m (70 ft) of relief on this surface beneath the WMA. The H3/Plio-Pleistocene unit (undifferentiated) averages about15 m (50 ft) thick over most of the waste site (Figure B-13), except to the northwest, where it is up to 30 m (100 ft) thick, and to the northeast, where it thins to about 10 m (30 ft).

2.2.8.2 Sand Sequence (H2 Unit). The Hanford formation sand sequence overlies the lower gravel sequence (H3 unit) and directly overlies the Hf/PPu(?) silt layer locally. The H2 unit is equivalent to the sandy sequence of the Hanford formation discussed in Last et al. (1989) and Lindsey et al. (1992), to the Hanford formation H2 sequence discussed in Lindsey et al. (1994), and to Qfs (Quaternary flood sands) documented in Reidel and Fecht (1994).

The H2 unit consists predominantly of the sand-dominated facies of the Hanford formation. Internally, this sequence probably contains multiple graded beds of plane- to foreset-bedded sand or gravelly sand several meters (feet) or more thick, which sometimes grade upward into silty sand or silt similar to that observed at the 218-E-12B Burial Ground (see Figure 2-8). Many more silt layers probably are present in the subsurface than are reported in driller's and geologist's logs and appear in the cross sections and fence diagram in Appendix A. This is because the drill method and/or the sampling interval (normally every 1.5 m [5 ft]) often cannot distinguish layers less than a few meters (feet) thick. Cementation is very minor or absent, and total calcium carbonate content generally is only a few weight percent or less.

The Hanford formation sand sequence (H2 unit) is ubiquitous beneath the B-BX-BY WMA. The base of the Hanford sand sequence lies at the top of the gravel-dominated sequence toward the bottom of the hole or at the top of the fine-grained Plio-Pleistocene unit, whichever is higher.

A structure-contour map of the top of the Hanford formation sand sequence is shown in Appendix B, Figure B-14. The map shows approximately 20 m (60 ft) of relief on the surface of the sand sequence beneath the B-BX-BY WMA. This sand sequence is thickest (60 m [200 ft]) in the central and southern portions of the WMA and thins to as little as 30 m (110 ft) to the north (Figure B-15).

2.2.8.3 Upper Gravel Sequence (H1 Unit). The Hanford formation upper gravel sequence overlies the Hanford formation sand sequence. This unit is equivalent to the upper gravel sequence of the Hanford formation discussed in Last et al. (1989) and Lindsey et al. (1992), to the Hanford formation H1 sequence discussed in Lindsey et al. (1994), and to Qfg documented in Reidel and Fecht (1994).

Based on observations of outcrop and intact core samples, the Hanford formation upper gravel sequence is interpreted to consist of the high-energy, gravel-dominated facies interbedded

with lenticular and discontinuous layers of the sand-dominated facies. Silt-dominated facies may also be present, though they probably constitute a relatively small percentage of the total.

The maximum thickness of the H1 unit reflects a north-south-trending trough (i.e., channel) that lies beneath the BX and BY tank farms. The maximum thickness of the H1 unit in this trough is about 20 m (60 ft) (Figure B-16).

2.2.8.4 Holocene Deposits. Locally up to 10 m (35 ft) of backfill material is present above the Hanford formation in many of the boreholes drilled in the B-BX-BY WMA.

2.2.9 Clastic Dikes

Clastic dikes are vertical to subvertical sedimentary structures that crosscut normal sedimentary layering. Clastic dikes are a common geologic feature of the Hanford formation in the 200 Areas, especially in the sand- and silt-dominated facies. Clastic dikes are much less common in the gravel-dominated facies of the Hanford formation. No clastic dikes were observed in the excavated walls of trench 94 in the 218-E-12B Burial Ground (see Figure 2-8), located about 1000 m (3,000 ft) east of the B-BX-BY WMA. However, they are occasionally observed elsewhere within the gravel-dominated facies of the Hanford formation.

Clastic dikes occur in swarms and form the following four types of networks (Fecht et al. 1999):

- Regular-shaped polygonal patterns
- Irregular-shaped polygonal patterns
- Preexisting fissure fillings
- Random occurrences.

Clastic dikes near the WMA probably occur randomly in the gravel-dominated facies (Hanford formation Units H1 and H3) and as regular-shaped polygons in the sand facies (Hanford formation unit H2). Regular-shaped polygonal networks resemble 4- to 8-sided polygons and typically range from 3 cm to 1 m (1 in. to 3 ft) wide, from 2 m to more than 20 m (6 to more than 65 ft) deep, and from 1.5 m to 100 m (5 to 325 ft) along their strike. Smaller dikelets, sills, and small-scale faults and shears are commonly associated with master dikes that form the polygons.

In general, a clastic dike has an outer skin of clay, with coarser in-filling material. Clay linings are commonly 0.03 mm to 1.0 mm (0.001 to 0.04 in.) thick, but linings up to about 10 mm (0.4 in.) thick are known. The width of individual in-filling layers ranges from as little as 0.01 cm to more than 30 cm (0.0004 to more than 12 in.) and their length can vary from about 0.2 m to more than 20 m (8 in. to more than 65 ft). In-filling sediments are typically poorly to well-sorted sand, but may contain clay, silt, and gravel (Johnson et al. 1999).

2.3 RECHARGE SOURCES AND EVENTS

The facility infrastructure, infiltration of water from natural and tank farm operation sources, and hydrologic properties of the stratigraphic units beneath the study area control the moisture and waste movement through the vadose zone to groundwater. This section summarizes available information on infiltration from natural resources, discharges caused by

tank farm operations and observed spatial and temporal effects on subsurface hydrologic properties. Supporting data tables and figures are provided in Appendix C.

Fluid infiltration into the soil column from the natural and tank operation sources, which are discussed in Sections 2.3.1 and 2.3.2, respectively, had a substantial effect on current environmental contamination conditions in the B-BX-BY WMA. Temporal changes in vadose zone moisture distribution and water table elevation in response to historical variations in natural and artificial recharge (Section 2.3.3), combined with aquifer properties, account for the rate and direction of contaminant dispersal in the aquifer.

2.3.1 Infiltration from Natural Sources

The tank farm surface characteristics and infrastructure create an environment conducive to enhanced general recharge and transient, high-intensity events. Natural infiltration, runoff events, and rapid snowmelt are discussed in Sections 2.3.1.1 through 2.3.1.3.

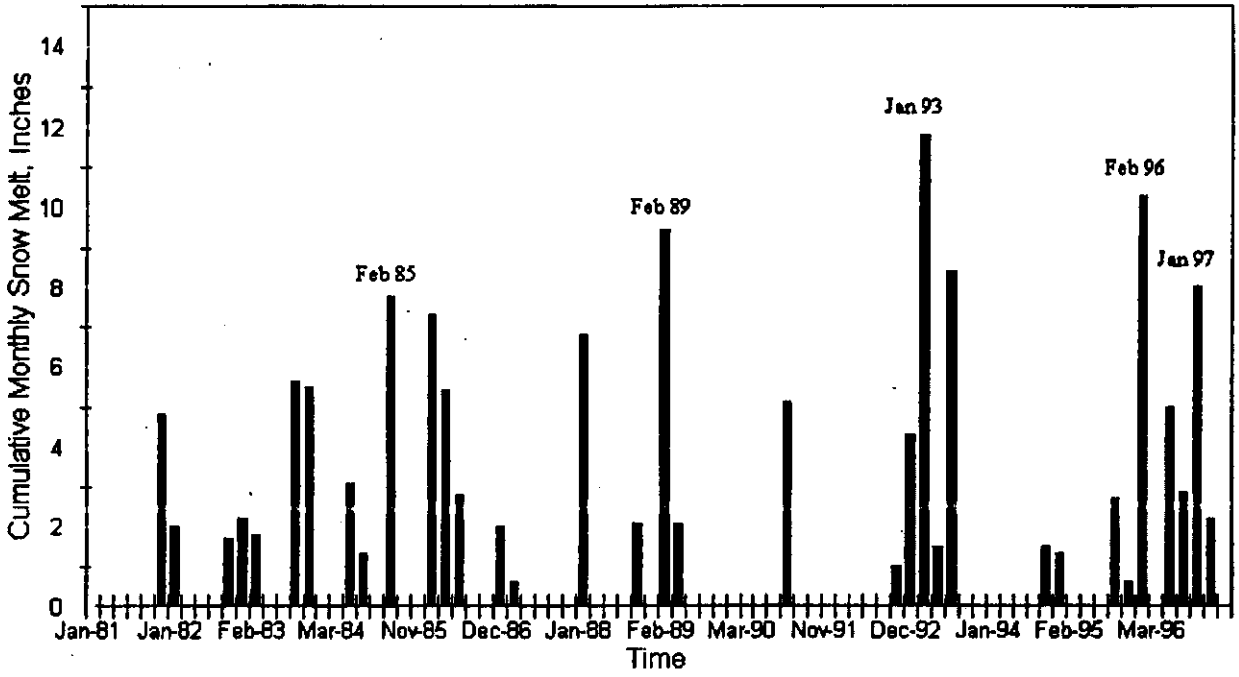
2.3.1.1 Infiltration. No direct measurements of the natural infiltration rate under the B-BX-BY WMA have been made. However, observations from similar, disturbed, gravel-covered areas at the Hanford Site indicate that as much as 10 cm/year (3.9 in./year) can infiltrate a vegetation-free coarse gravel surface (Gee et al. 1992; Fayer and Walters 1995; Fayer et al. 1996). This represents about 60 percent of the average annual meteoric precipitation (rainfall plus snowmelt). Fayer and Walters indicate that the B-BX-BY WMA is in an area estimated to have about 2 cm/year to 5 cm/year (0.8 to 1.97 in./year) of infiltration based on soil type, vegetation, and land use and infiltration rates of 5 cm/year to 10 cm/year (1.97 to 3.9 in./year) immediately south of the tanks. Actual recharge is significantly different and not uniform because of the presence of the tanks and the disturbed soil surrounding the tanks. Recharge is intercepted and "shed" by the tank domes and flows into the disturbed soil near the tanks. Thus, infiltration rates near tank edges and between rows of tanks are likely manifold higher than average areal infiltration rates. Also, net infiltration is increased because the vegetation has limited uptake during these intense and rapid infiltration events.

2.3.1.2 Runoff Events. Transient saturation from runoff collecting in low spots may be more significant as a driving force than average annual infiltration. For example, rapidly melting snow is one natural event that can lead to surface flooding. This type of occurrence has been documented at other tank farms (e.g., T tank farm [Hodges 1998]), but no similar record is available for the B-BX-BY WMA. However, waterline ruptures, such as the one in September 1996 at the S tank farm, demonstrate that surface water could enter and collect in low spots (Johnson and Chou 1998). One topographical low at this WMA is located at the junction of the northwestern corner of the BY tank farm and the elevated soil barrier over the 216-B-57 crib. Within the boundaries of the tank farms, ponding can be controlled by the berms constructed over electrical lines. These barriers provide potential locations for water to collect during unusual runoff events.

2.3.1.3 Rapid Snowmelt. Records of snowmelt have been made since 1981 at the Hanford Meteorology Station, located between the 200 West and 200 East Areas. Figure 2-9 summarizes the total snow melt per month for 24 hours. These records indicate likely periods when unusual accumulations or ponding of water may have resulted in transient saturation events, possibly leading to transport of contaminants through the vadose zone to groundwater. The snowmelt

events, as well as maximum monthly precipitation since 1946 (Appendix B, Table B-1), are correlated with groundwater contamination occurrences in Figure 2-10.

Figure 2-9. Monthly Summaries of Rapid Snowmelt Events, 1981 Through 1997.



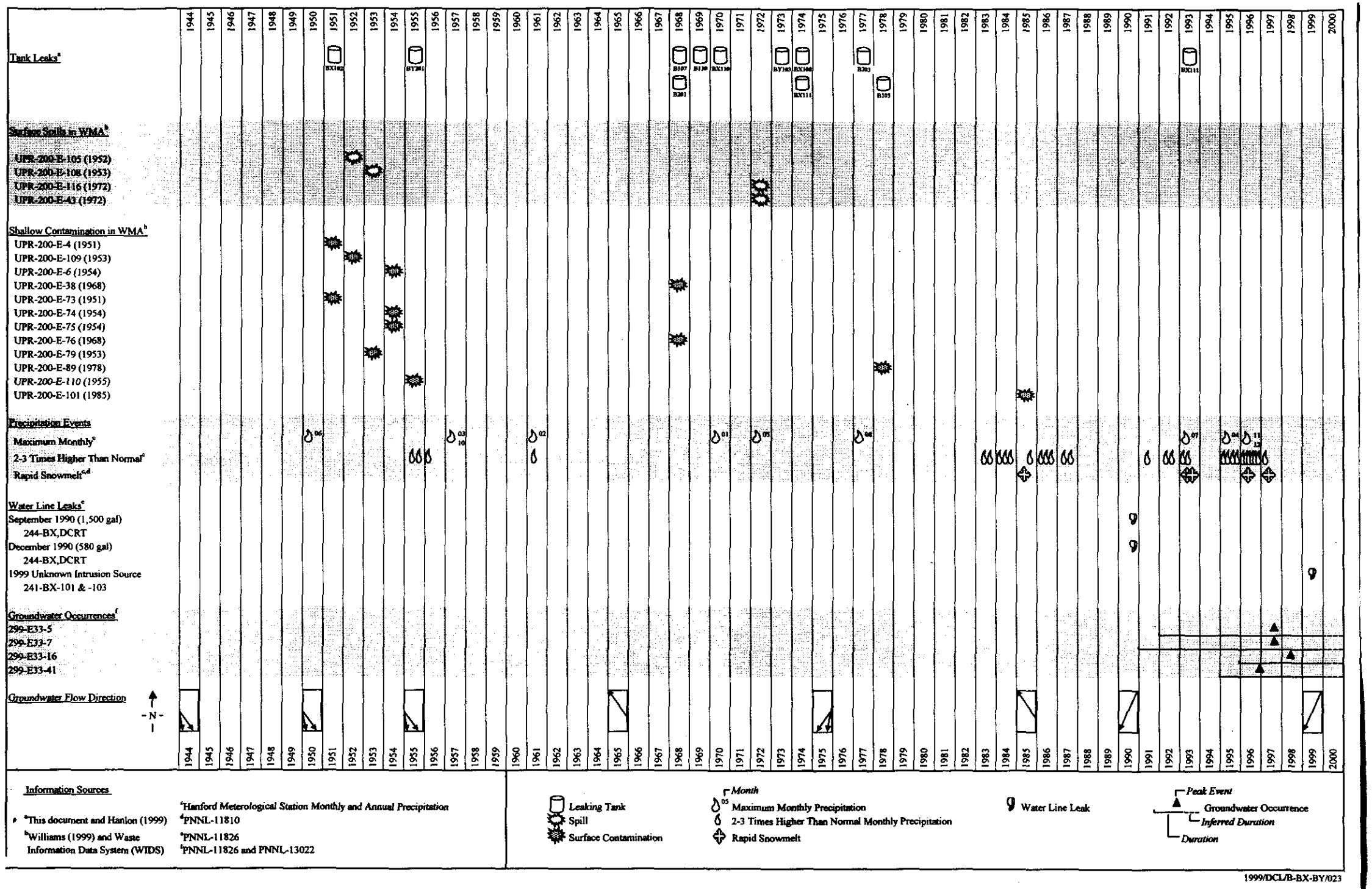
2.3.2 Fluid Discharges from Tank Farm Operations

Throughout the operational history of the B-BX-BY tank farms, fluids were discharged, both deliberately and inadvertently. To a large extent, the current state of environmental contamination has been caused by these discharges. Key characteristics include the location and time, volume, and contaminant inventory of these discharges. Where available, contaminant inventory information is summarized in Chapter 3. A more detailed discussion of these events is provided by Williams (1999). Data and narrative from Williams (1999) are provided in Appendix A.

Fluid discharge from the B-BX-BY tank farm complex occurred outside and inside the B-BX-BY WMA. Substantially greater volumes of waste fluids were deliberately discharged outside the B-BX-BY WMA. These releases occurred in four primary locations to support the major operations involving the B-BX-BY tank farm complex.

First, during the early stages of the bismuth phosphate operations, tank waste fluids were deliberately released to cribs and wells just north of the B tank farm. Cribs 216-B-7A and 216-B-7B received 1,135,440 gal and Crib 216-B-8 received 713,265 gal of waste fluids from 1946 to 1957. The majority of fluids were disposed of by 1953. Reverse wells 11A and 11B, which released fluids directly to the unconfined aquifer, received 781,949 gal of waste from 1951 to 1954.

Figure 2-10. Time Line of Hydrologic and Tank Farm Operational Events.



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Third, TBP waste from the uranium recovery program was discharged to BX trench 216-B-42 (39,626 gal) and the BY cribs (898,185 gal) in 1954 and 1955.

Fourth, as part of tank stabilization, condensates from tank liquids were discharged into BY crib 216-B-50 (1,558,862 gal) and 216-B-57 (2,219,045 gal), just southwest of the BY cribs.

Discharges within the B-BX-BY WMA were unplanned releases. These are listed in Appendix A in the table captioned "Appendix 2: Unplanned Release Quantities." Quantities are not known for many of the identified releases. Reported releases are primarily leaks from transfer pipelines, diversion boxes, and tanks. The most significant release, in terms of quantity and degree of contamination is the loss of metal waste from tank BX-102 in 1951. Metal waste was the initial waste stream produced in the plutonium extraction process and contained the highest concentrations of radionuclide constituents. Approximately 91,589 gal of waste were released. The second largest reported release (70,006 gal) is a tank leak from BX-102. However, evidence documenting this release is questionable. Smaller leaks from an overground pipe (22,873 gal of 1C bismuth phosphate waste), a flush tank overflow (10990 gal of TBP waste), another pipe leak (5,400 gal), and leaks from various single shell and auxiliary tanks (8,321 gal or less) also are listed.

The following occurrence reports and tank farm operations information are listed and briefly described for use in Figure 2-10, which describes the time line of hydrologic and tank farm operational events. These reports document that artificial water sources that existed in the past could have remobilized waste in the vadose zone associated with the 241-BX-102-tank leak. Furthermore, flooding occurred that might have caused the nearby vadose contamination observed during drilling to spread to the present location of well 299-E33-41. Several of the following occurrences describe water-line leaks and valve ruptures at the 244-BX receiving tank, located about 45.7 m (150 ft) south of well 299-E33-41 (see Figure 2-1). This water likely remobilized tank waste while well 299-E33-41 was being drilled.

- Tank Farm-1990-0054, September 1990. Raw water was found discharging from a 1.3 cm (0.5-in.) line onto the ground from the exterior wall of the 244-BX double-contained receiving tank (DCRT) located just south of well 299-E33-41 (see Figure 2-1). Although a leak-detection alarm sounded and the area was checked, the open line was not discovered. Approximately 4.5 hours later, an open valve was found in the DCRT building. How long the water flowed onto the ground before the alarm activated was not reported. A 1,500-gal increase was observed in the DCRT, but no estimate was given on the total volume of liquid released to the soils. However, the open valve reportedly finally was noticed because a pool of water adjacent to the 244-BX DCRT pump pit was discovered.

- Tank Farm-1990-0373, December 1990. Subzero weather conditions caused raw water piping in the 244-BX DCRT building to rupture several valves. No estimate was made of the amount of water discharge to the surrounding soil. Approximately 550 gal of water drained into the 244-BX DCRT via the 244-BX flush pit floor drain. Excess water also had to be removed from the flooded instrument building. It is important to note that drilling began in January 1991 for well 299-E33-41, located approximately 48.8 m (60 ft) north of 244-BX DCRT, where the terrain slopes slightly downward toward the north.

- Tanks 241-BX-101 and 241 BX-103. Two single-shell tanks, close to well 299-E33-41, were placed on the candidate intrusion list indicating possible liquid intrusion into the tanks (Hanlon 1999). Both tanks 241-BX-101 and -103 have been interim stabilized. Tank 241-BX-101 is an assumed leaker and tank 241-BX-103 is assumed to be sound. These tanks were placed on the intrusion list because surveillance data show that the surface levels in the tanks have met or exceeded the increase criteria. Both tanks are on the eastern side of the BX tank farm, near well 299-E33-41. The source of the liquid that may be intruding into these tanks is unknown.

- Raw and Sanitary Water Lines. As built diagrams show 1.5 and 10 cm (4- and 6-in.) raw water lines and 3.8 cm (1.5-in.) sanitary water lines running north-south along Baltimore Avenue and along the farm fence lines. These lines run past 244-BX-DCRT and next to well 299-E33-41. Also, until recently, the BY tank farm had pressurized water lines inside the tank farm fence lines. Near-surface concentrations of contaminants close to water line leaks could be another source of groundwater contamination. Although rarely documented as important events, water-line leaks have occurred, as is common with any water system. The lack of records makes determining or documenting any significant effect on contaminant mobilization or transport difficult.

2.3.3 Subsurface Discharge

2.3.3.1 Vadose Zone Moisture Distribution.

Substantial fluid volumes of tank waste and tank waste condensates were discharged into cribs and trenches adjacent to the B-BX-BY WMA. These fluids could have migrated laterally into the vadose zone beneath the B-BX-BY WMA. However, no evidence exists to indicate that such lateral migration has occurred. Given that more than 20 years have passed since crib and trench discharges adjacent to the B-BX-BY WMA occurred and that the soils are highly permeable, any fluids from these sources have likely migrated from the cribs and trenches downward toward the water table. Based on data collected during a surface barrier study conducted adjacent to the BY tank farm, 30 to 50 percent of the annual precipitation was found to drain through bare gravel and rock cover materials (DOE 1999) near the B-BY-BX WMA over the past 4 years. Based on the surface barrier data, a likely recharge scenario, is that 40 percent of the annual precipitation will drain, primarily as a result of deep infiltration of winter precipitation, when evaporation conditions are low and will produce an average recharge flux rate of 70 mm/yr. Because the average water content in the coarse sediments is about 10 percent by volume, the pore water velocity will be 10 times the recharge rate or 0.7 m per year. Assuming no fast pathways (vertical channels, etc.) the expected limit of fluid migration is approximately 14 m below the original depth of the leak (Ward et al. 1997). It should be noted that the cribs and trenches received millions of gallons of discharge water. These large "volumes" would likely extend to groundwater, particularly in and near the cribs. During the past 20 years, discharge liquids would have been flushed about an additional 14 m downward to the water table by precipitation, not that the actual discharge liquids are only 14 m below the crib bottom.

In the months before well 299-E33-41 was drilled, several flooding events occurred just south of this well's location at the 244-BX-DCRT. The migration through the vadose zone of water from these floods while well 299-E33-41 was being drilled would explain the series of high-radiation concentrations in a series of silt lenses from 22.3 m to 73.2 m (73 to 240 ft) and the contaminated perched water zone at 68.3 m (224 ft) below the ground surface. The actual water-table surface at this time was 75.3 m (247 ft) from the ground surface. Well 299-E33-41 is close to the site of the metal waste leak from 241-BX-102. This tank leak is most likely the original cause of the contamination because it is only 11.3 m (27 ft) from the well. The nearest crib is 216-B-7B, 91.4 m (300 ft) from the well.

2.3.3.2 Water Table and Artificial Recharge.

The water table has changed significantly since tank farm operations began in the early 1950s. The shift in discharge of large volumes of wastewater in the early 1950s raised the water table in the vicinity of the study area to over 4.9 m (16 ft) above the level before Hanford Site operations (Figure 2-11). The flow direction should be turning back to the original pre-Hanford direction, which is assumed to be to the southeast. This expected flow direction change would be in response to the diminishing B Pond mound located about 0.6 km (1 mi) east of the B-BX-BY WMA. Water levels are declining rapidly, as shown in Figure 2-11. As a result, in 5 to 8 years, some wells will contain little water. Given the transient hydrological conditions in this region, long-term water levels are difficult to predict.

Figure 2-11. Historical Water Levels Near the B-BX-BY WMA.

2.4 HYDROLOGIC PROPERTIES

2.4.1 Vadose Zone Properties

A summary of vadose zone hydrologic properties collected at the Hanford Site is provided in Khaleel and Freeman (1995). A subset of this database is included in Appendix C, Table C-1. The most pertinent data were collected on Hanford formation soils underlying the BY cribs during the remedial investigation of the 200-BP-1 operable unit. Given the proximity of the soil locations, these data are considered to be waste site-specific. The database includes the location of the sample, the depth at which the sample was collected, particle size distribution, moisture retention curve data, and saturated hydraulic conductivity values. Generally, the soils are variable mixtures of sands and gravels. Well-defined horizontal strata with distinctly different hydraulic properties favoring lateral movement in the vadose zone (e.g., silty sands) are probably present locally, but are not widespread.

2.4.2 Aquifer Properties

This section provides information on the current nature of the unconfined aquifer in the immediate region of the B-BX-BY WMA. Aquifer properties were determined from stratigraphic interpretations, current water elevations, and hydraulic conductivity values based on aquifer tests. Details are provided in Hartman (2000).

The water table lies in basal gravels interpreted as fluvial pre-Missoula sediments, extending upward at places into unit H3 of the Hanford formation. As explained in Section 2.2.7, the water table rests within these loose, sandy gravels, displaying primary grain sizes that range from cobble- to boulder-sized clasts. The aquifer thickness varies from 2.1 m to 4.3 m (7 to 14 ft) across the site, depending on the location of local highs in the basalt surface. The aquifer appears to be thicker where the basalt surface is lower, correlating with the structure on the top of the basalt. Additional reductions in aquifer thickness are plausible as the effects of abandoned Hanford liquid discharge practices on unconfined aquifer hydrogeologic characteristics dissipate. Quantitative estimates of future steady state aquifer thicknesses are highly uncertain.

The hydraulic gradient is flat across the 200 East Area. With about 10 cm (4 in.) of change across the WMA, the use of discrete water elevations to determine flow direction is complicated. In this region, making comparisons of data between individual wells to determine the upgradient versus downgradient locations is difficult. This difficulty is related to the fact that the total error in water elevations can be a significant portion of the actual differences in water elevation between two wells.

Part of this discrepancy is related to survey error. In 1998, the Hanford Groundwater Monitoring Project changed the datum to which water levels are referenced (Hartman 1999). The geodetic elevation datum currently used is NAVD88. The NAVD88 protocol standard for geodetic elevation data is the new general adjustment of the North American Vertical Datum of 1988. Specifically, NAVD88 is a minimum constraint adjustment of Canadian, Mexican, and United States leveling observations. The adjustment was performed holding the height of the primary title benchmark fixed. This adjustment is referenced to the new International Great

Lakes Datum of 1985 (IGLD85), local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. The datum is not mean sea level, a geoid, or any other equipotential surface.

This type of National Geodetic Survey (NGS) vertical control datum is a set of fundamental elevations to which other elevations are referred. In the early 1990s, the U.S. Army Corps of Engineers surveyed about 1,500 wells under the command of John Chance, with the NGS involved in the planning. The Corps adjusted both the NAVD88 and NAVD29 data for the environmental restoration contractor. However, because the NGS no longer supports NAVD29, whenever possible all actively monitored wells are now referenced to the vertical control datum NAVD88. However, doing this was not practical for the water-level data presented in this section, and the NAVD29 was used for water-level interpretation. The NAVD88 elevations are about 1 m higher than NGVD29 elevations in the vicinity of the Hanford Site. Converting elevations to NAVD88, using a software package called Corpson (Version 5.11, U.S. Army Corps of Engineers 1997), which uses the VERTCON software program (Version 2.0) developed by NGS, can contribute errors of approximately 1 cm (0.4 in.).

More important to the amount of error between water levels in wells than the selection of the vertical control datum is the choice of the specific survey used to calculate water-level elevations. Many vertical surveys of wells have been conducted at the Hanford Site over the last 50 years. The most accurate survey probably is the one done by the Corps that was mentioned in the previous paragraph. However, direct measurements between well pairs are rare. Consequently, errors between any two wells cannot be determined. Only errors between wells and their control point or network of survey points from which the measurements were made can be determined. Therefore, the accuracy in well elevation or location is the amount of known error in the survey, which almost always is greater than the actual error between any two wells in the survey (Schalla et al. 1992). If separate vertical surveys are conducted on different groups of wells, the amount of estimated error would probably be at least equal to the composite error of all the surveys. A comparison of well elevations, based on different surveys in the B-BX-BY WMA, gives results that differed as much as 50 percent of the gradient across the Site. Water elevations are the most direct method to determine the direction of groundwater flow in the aquifer, but comparing water-level elevations from different surveys can be confusing and lead to incorrect conclusions.

The potential errors complicate the use of water table maps to estimate flow direction. Indeed, the regional water-table map for the 200 East Area shown in Hartman (2000) provides contours through the area. Any comparisons or attempts to determine an accurate flow direction at the B-BX-BY WMA, based on one contemporaneous set of water levels, are subject to interpretation.

However, with care, a general flow direction can be determined. Figure 2-11 shows hydrographs for 11 wells currently used to monitor the water table at the B-BX-BY WMA and the nearby Low-Level Burial Ground (LLBG) 1 and LLBG2 WMAs. Most of the water elevations are referenced to a 1992 survey based on NGVD29. This survey was used in preference to multiple surveys based on NAVD88 for the following reasons.

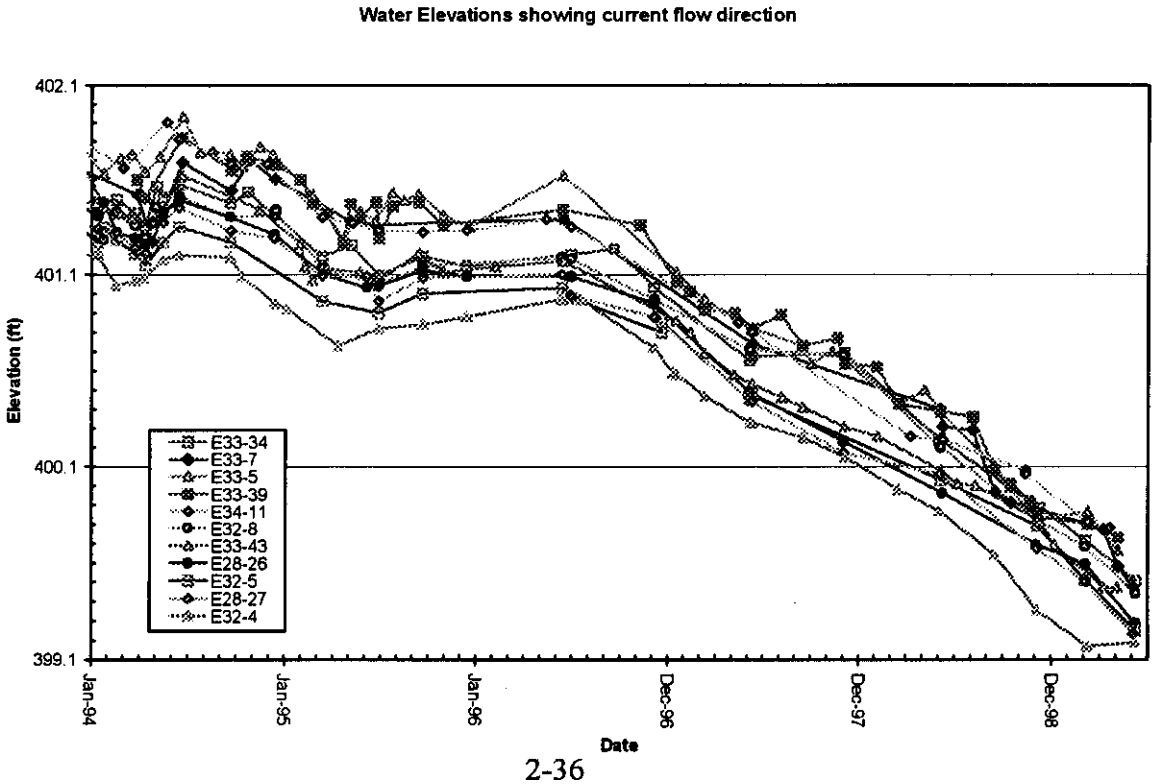
- Most of the wells in the northeastern corner of the 200 East Area were included in this 1992 well survey.

- With only a few centimeters (inches) of change across the Site, introducing additional error associated with calculating a NAVD88 datum from the NGVD29 datum for different surveys was avoided.

Care was taken to compare available elevations from different surveys for each well to ascertain the validity of the survey data. If a significant discrepancy was found, a newer survey based on NGVD29 was used for that well or the well's data were eliminated. In addition, as part of the *Resource Conservation and Recovery Act of 1976* (RCRA) assessment work conducted by the Hanford Groundwater Monitoring Project, vertical plumbness was measured in several wells that appeared to complicate the interpretation of local flow. Well 299-E33-39 was surveyed in fiscal year (FY) 1999 because data from that well consistently displayed anomalous low water elevations. Based on deviations from vertical, determined with a downhole gyroscope, a 12 cm (0.4-ft) correction was added to the water levels in this well.

The data from selected wells shown in Figure 2-12 depict the general local water-level trend. Spurious and outlying data were removed from the individual well trends to facilitate interwell comparisons. All well water elevations decrease over time. However, the relative elevations between wells are maintained rather consistently over time. Wells E-33-34, E-37-7, E-33-5, E-33-39, E-34-11 and E-32-8 show higher elevations than wells E-33-43, E-28-26, E-32-5, E-28-27, and E-32-4 at any given time. The location map in Figure 2-13 clearly shows that the upgradient water elevations are in the north. This indicates a southwest flow direction. Although data from a few wells in this area do not agree with the trend shown in Figure 2-12, the majority of wells for which consistent survey information is available appear to mirror this general southwest flow.

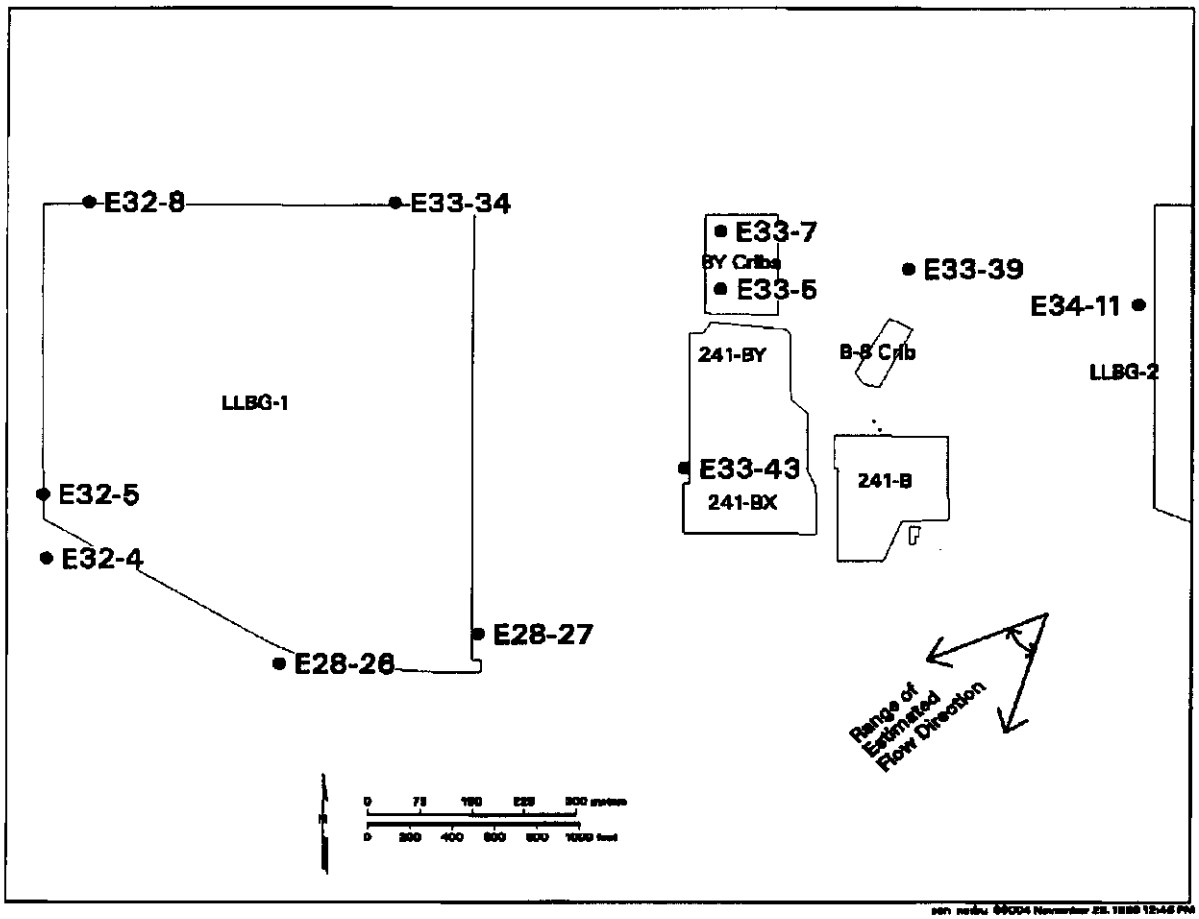
Figure 2-12. Hydrographs for 11 Wells Located North, East, West, and Southwest of the B-BX-BY WMA. (Wells E33-34, E33-7, E33-5, E33-39, E34-11, E32-8, and E33-34 are upgradiant; the rest are downgradient.)



As stated earlier and as can be seen in the hydrographs, determining flow using a selected contemporaneous data set to determine a single flow direction could be misleading. Consequently, it may not be appropriate to provide a three-point solution. However, based on observations of recent contaminant movement and on wells that consistently appear to be at the same relative elevations, an estimated flow direction lies between 200 and 250 degrees azimuth as shown in Figure 2-13.

The rate of groundwater flow for RCRA sites is calculated for a homogeneous, isotropic aquifer from the Darcy equation shown in Hartman (2000). This simple, one-dimensional equation incorporates the effective hydraulic conductivity, the local water-elevation gradient across the Site, and an estimated aquifer porosity. The local hydraulic conductivity of 1600 m/day (5,300 ft/d), based on aquifer test results, was reported in Newcomer et al. (1992) and Connelly et al. (1992). Porosity is estimated as 30 percent or greater for the unconsolidated gravels that made up the aquifer. Unfortunately, collecting intact core from the aquifer in sufficient quantity is difficult because of large grain size. Consequently, direct methods of determining porosity have not been used. Given the lack of direct measurements, combined with the cobble-to-boulder nature of the aquifer, 30 percent may be a low estimate. The local hydraulic gradient across the B-BX-BY WMA is approximately 0.00017, based on September 1999 water levels. Future changes in gradient values are likely as the effects of abandoned Hanford liquid discharge practices continue to dissipate.

Figure 2-13. Location Map for Wells Shown in Figure 2-12.



Using these parameters, the effective flow rate is calculated to be 0.9 m/day (3 ft/day). This equates to 324 m (1,064 ft) of effective groundwater movement per year. If discrete, high-permeability flow channels are considered as the primary avenues of contaminant transport, a flow rate of 0.9 m/day (3 ft/day) may be low. This relatively high flow velocity has implications that relate to the optimal sampling frequency at which the groundwater is monitored. Because the WMA is approximately 400 m (1,300 ft) long from north to south and 300 m (985 ft) from east to west across the 241-BY tank farm, contamination related to leakage of tank waste might move through the area in less than 1 year. Given the pulse-type events seen in the past at well 299-E33-41 and the high frequency of contamination documented at the S-SX WMA, semiannual or even quarterly sampling may not be sufficient to clearly identify and differentiate tank-related waste from background contamination left from discharges to the surrounding cribs, trenches, and reverse wells (Johnson and Chou 1998; Narbutovskih 1998). As part of the RCRA B-BX-BY WMA assessment, a study is currently being conducted to determine the best sampling frequency for monitoring this WMA.

2.5 GEOCHEMISTRY

This section covers geochemical factors and material properties of the vadose zone and unconfined aquifer underlying the B-BX-BY WMA that control contaminant mobility in the soil column. Radionuclide and hazardous-constituent mobility can be substantially different depending on the innate characteristics of the contaminant and the geochemistry of the soil-water system. In these soils, both factors are expected to be important. Different contaminants present in the soils are variably mobile and, depending on interactions of tank fluids with the soil-water system, a given contaminant's mobility can be considerably different at different locations and times within the vadose zone and unconfined aquifer.

The geochemical characteristics and contaminant mobility are best considered in terms of behavior in relatively undisturbed soils versus soils that have interacted with tank waste fluids. In addition, tank fluid chemistry varies. Both types of soil conditions are expected in the vadose zone underlying the B-BX-BY WMA. For relatively undisturbed soils, a substantial Hanford Site-specific, but not B-BX-BY WMA-specific, database is available that quantifies geochemical characteristics and contaminant behavior, particularly for radionuclides (e.g., Ames and Rai 1978; Serne and Wood 1990; Serne et al. 1993; Kaplan, Parker, and Kutynakov 1998, and Kaplan and Serne 1999). Average soil properties are described in Section 2.2. Soil water in the vadose zone and groundwater in the unconfined aquifer have similar characteristics. They are moderately alkaline (pH about 8) and contain moderated concentrations of cations and anions. Dominant cations are calcium (about 50 mg/L), magnesium (about 14 mg/L), sodium (about 30 mg/L), and potassium (about 9 mg/L). Dominant anions are carbonate (about 70 mg/L) and sulfate (75 mg/L).

Within the B-BX-BY WMA, geochemical and related soil property data have not been collected. However, an extensive soil sample and analysis program was conducted in the soils underlying the BY cribs just north of the B-BX-BY WMA as part of the 200 BP-1 Operable Unit remediation investigation (DOE/RL 1993). At most depths in the undisturbed soils, the fraction of gravel-size particles (larger than 2 mm) dominates. The exceptions are a sand-dominated soil at about 40 to 60 m below the surface and a silty sandy soil at about 95 m below the surface. The upper layer is more or less continuous at 58 m to 59 m throughout the BY crib area. A mineralogical analysis was not performed.

One Site-specific study of radionuclide sorption tendencies was completed as part of the remediation investigation (DOE/RL 1993). This report is provided in Appendix D. Batch sorption experiments were completed for ^{60}Co, ^{90}Sr, ^{99}Tc, plutonium, and cyanide using local soils and groundwater. Measured sorption coefficient values for ^{90}Sr, ^{99}Tc, and plutonium were in the expected range for standard undisturbed soils and groundwater chemistry (5 mL/g to 10 mL/g, 0 mL/g, and more than 1000 mL/g, respectively). As expected, cyanide sorption was very low. Cobalt-60 sorption also was very low (less than 1 mL/g) indicating the presence of a complexing agent acting to form anionic aqueous species with ^{60}Co. Additional tests were performed in the presence of various initial concentrations of cyanide and EDTA. Cyanide effectively reduced ^{60}Co sorption at both concentrations (150 and 2,000 ppb) used and EDTA also greatly reduced ^{60}Co sorption at the higher concentration (2,000 ppb).

These results are not definitive. The use of cyanide versus ferrocyanide in these experiments makes the relevance of the results ambiguous. The quantities of EDTA used experimentally are much greater than expected in the waste stream. Given the historical record of adding ferrocyanide during waste processing, a potential complexing agent may be cyanide if cobalt exchange with iron is favorable. However, the kinetics and mechanisms of this and other potential reactions that might lead to the formation of cobalt complexes are unknown. Other species known to be present in the waste, such as carbonate and ammonia, are potential complexing agents for cobalt.

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3.0 TANK WASTE CHEMISTRY AND LEAK CHARACTERISTICS

The tanks in the B, BX, and BY tank farms were used from the mid-1940's through 1980 to store waste of a wide variety of types. The operational histories of these tank farms are summarized in Williams (1999) (narrative and tables attached as Appendix A) and Section 2.1.2. A number of tanks in these farms are known or suspected to have leaked and significant evidence exists of near-surface leaks in and near these tank farms. In addition, millions of gallons of tank waste were intentionally discharged to cribs and trenches within 150 m of the tank farms. The subsurface contamination in and around these tank farms reflects the complexities of their long-term operating histories.

3.1 GAMMA RAY LOGGING INFORMATION

Two types of gamma ray logging data were collected in the B, BX, and BY tank farms. As part of a tank leak detection program (Isaacson and Gasper 1981), gross gamma logging was conducted from the early 1960's through 1994. Recently, the gross gamma logging data from tank farms BX and BY were evaluated to assess potential movement of gamma-emitting radionuclides in the vadose zone (Myers 1999a, 1999b).

3.1.1 Spectral Gamma Ray Logging Data

Comprehensive spectral gamma logging of all drywells in the B-BX-BY WMA were completed between 1997 and 1999. Spectral gamma logging reports were available for the BX (DOE-GJ 1998a) and BY (DOE-GJ 1997) tank farms. The spectral logging report for the B tank farm was not available at the time of this assessment. A preliminary assessment of the B tank farm was developed using available reports for individual B farm tanks. Drywell location maps in each tank farm and summary figures of the individual drywell spectral gamma logs are provided in Appendix E.

Specific examples of the use of gamma logging data to assess potential tank leak scenarios are included in the discussion of specific tank farms (see Section 3.3). In some cases, the spectral gamma data provide information that can be correlated with time-dependent waste transfer and storage records for specific tanks. This allows identification of specific waste types. The spectral gamma data also provide an independent means of evaluating the veracity of reported tank leaks.

Some limitations are associated with the gamma logging methods. These must be considered in evaluating the referenced data reports. First, gamma logging interrogates only about 30 cm to 45 cm (12 to 18 in.) of the soil around the well. Second, uncertainties associated with distinguishing gamma contamination in the well or on the well casing from gamma activity originating in the soil may make data inaccurate. Finally, gamma activity monitored by these methods provides little information about the tank waste-related non-gamma-emitting radionuclides and chemicals. Nevertheless, the gamma logging data summarized in the referenced reports provide the most comprehensive data set available for assessing the nature and extent of gamma contamination in the soil column under this WMA.

3.1.2 Synthesis of BX and BY Tank Farm Historical and Spectral Gamma Logging Data

Because gross gamma logging was conducted over two decades, evaluating these data provides information on the time-dependent behavior of the gamma-emitting radionuclides in the subsurface. Two reports have been issued on this subject, one for the BX tank farm (Myers 1999a) and one for BY tank farm (Myers 1999b). A third report is being written for the B tank farm.

The concentrations of the individual gamma-emitting isotopes that contributed to the gross gamma curves over time were estimated using the recently collected spectral gamma data (concentrations of specific gamma-emitting radionuclides) from the drywells used to collect gross gamma data. By factoring in decay, these calculated curves were propagated over time and compared with the gross gamma curve histories. Using this process, we frequently can distinguish between changes in the curves caused by simply decay or decay plus changes in gamma radionuclide concentrations at a given location over time.

Appendix E summarizes the results for the BX and BY tank farms. The charts show only the results indicating a change in radionuclide concentrations at a given location over time. These conditions are referred to as unstable events. For each location, the borehole number, the depth below the surface, the radionuclide present, the time over which changes in concentration were deduced, and the concentration increase or decrease over that period are listed. Also, near-surface changes assumed to be caused by tank farm operations are broken out separately.

Appendix E also lists the changes in radionuclide concentration over time in the BX and BY tank farms attributed to tank farm activity (Table 3 in both the BX and BY discussions). The changes occur within 6 m (20 ft) of the surface and generally from 1975 to 1985 over most of the tank farm areas. This observation is consistent with a common drywell spectral gamma pattern in which a maximum radionuclide concentration of 10 pCi/g to 100 pCi/g or occasionally higher (usually ^{137}Cs) near the surface diminishes with depth to about 1 pCi/g 6 m to 9 m (20 to 30 ft) below ground. We consider this pattern to be consistent with surface or near-surface leaks of contaminated fluid.

The remainder of the radionuclide change events listed (Table 8 in the BX discussion and Tables 6 and 10 in the BY discussion) occur at depths near the tank bottoms or lower. No leak source is suggested for these occurrences. Over the time during which measurements were taken, unstable conditions were observed in six drywells in the BX tank farm. In the BY tank farm, unstable conditions were observed in 26 drywells. In three of the BY tank farm drywells, data collected at various depths and times suggest vertical movement of specific radionuclides over a period of years. These include the movement of ^{125}Sb from about 19 m to 30 m (62 to 100 ft) between 1975 and 1991 in drywell 22-08-02, movement of ^{60}Co from 13 m to more than 29 m (42 to more than 95 ft) between 1975 and 1987 in drywell 22-07-02, and movement of ^{60}Co from 23 m to more than 30 m (74 and more than 100 ft) in drywell 22-07-09 between 1975 and 1994. Downward movement of ^{60}Co in drywell 22-03-09 is shown in Appendix E, Figure E-41. At the 24 m to 25 m (78 to 82 ft) depth interval, ^{60}Co concentrations rise and fall from 1975 to 1983. Since 1983, no ^{60}Co was added to these soils and concentrations decrease at a rate consistent with radioactive decay.

These data suggest that vertical movement in the vadose zone occurred rather easily for mobile radionuclides inside the BX and BY tank farms over the 20-year span. Also, in most cases, radionuclides identified as migrating are the most mobile species, ^{60}Co, ^{106}Ru, and ^{125}Sb. Cesium-137 migrations also are identified, but tend to be associated with near-surface tank farm activity releases or suspected tank leaks. These observations suggest that recharge is significant under present conditions, and mobile radionuclides in the vadose zone underlying these tank farms could reach groundwater in decades or less.

3.2 B-BX-BY WMA TANK WASTE CHEMISTRY AND LEAK HISTORY

Four main processing operations generated the variety of waste stored in the B, BX, and BY tank farms and discharged to the soil column. These were the bismuth phosphate plutonium extraction, uranium recovery, in tank solidification, and $^{137}Cs/^{90}Sr$ recovery (see Section 2.1.2 and Appendix A). This section summarizes available information about the chemistry of the waste from these operations and its ultimate distribution in the B-BX-BY WMA and associated facilities.

The B Plant operated from 1945 through 1952, recovering plutonium from irradiated fuel rods using the bismuth phosphate ($BiPO_4$) process. The three major waste streams from the $BiPO_4$ process coming to these tank farms were metal waste, first cycle waste, and second cycle waste. The metal waste contained essentially all the uranium and approximately 90 percent of the fission products. The first cycle waste stream was chemically similar to the metal waste except it did not contain much uranium and contained only about 10 percent of the fission products. The second cycle waste stream was chemically similar to the first cycle waste stream except it contained only about 0.1 percent of the fission products. A fourth waste type, generated from the aluminum cladding removal process, was added to the first cycle waste stream. Of these waste types, large quantities of first and second cycle waste were released to the soil column intentionally. Unplanned releases of metal waste and first cycle waste also are reported (see Appendix A and the table in Appendix A titled "Appendix 1: Intentional Release Quantities"). The nominal compositions of the $BiPO_4$ waste streams, as identified in Anderson (1990), are listed in Table 3-1.

Table 3-1. $BiPO_4$ and Uranium Recovery Process Waste Streams. (2 sheets)

Waste type	Constituent	Concentration
Cladding waste	$NaAlO_2$	1.2 M
	NaOH	1.0 M
	$NaNO_3$	0.6 M
	$NaNO_2$	0.9 M
	Na_2SiO_3	0.02 M
	SpG	1.19
	Plutonium	0.4%
	Uranium	0.4%
Metal waste	Uranium	0.5 lb/gal
	OH	0.71 M
	CO_3	2.4 M
	NO_3	2.7 M
	PO_4	1.4 M

Table 3-1. $BiPO_4$ and Uranium Recovery Process Waste Streams. (2 sheets)

Waste type	Constituent	Concentration
Metal waste (continued)	SpG	1.86
	Sodium	4.8 M
	Plutonium	1 percent
First cycle waste	$CePO_4$	<0.01 M
	$Zn_3(PO_4)_2$	<0.01 M
	$NaNO_3$	0.85 M
	$Fe_2(SO_4)_3$	0.07 M
	Na_3PO_4	0.75 M
	$Cs(NO_3)$	<0.01 M
	$(NH_4)_2(SO_4)$	0.04 M
	$NH_4(SiFe)$	0.07 M
	NH_4NO_3	0.06 M
	Plutonium	1%
Second cycle waste	$BiPO_4$	0.08 M
	LaF	<0.01 M
	KOH	0.45 M
	KNO_3	0.01 M
	$NaNO_3$	0.34 M
	$Cr(NO_3)_3$	0.02 M
	NaF	0.03 M
	$Mn(NO_3)_2$	0.02 M
	NH_4NO_3	0.01 M
	Plutonium	1%
Scavenged tributyl phosphate waste (uranium recovery waste)	pH	≥9.5
	Phosphorous	1.29
	UNH	0.0026 M (5.2×10^{-3} lb/gal)
	SO_4	0.346 M
	PO_4	0.25 M
	NO_3	6.14 M
	Chlorine	0.022 M
	Sodium	7.57 M
	OH	0.094 M
	Fission products	1%

The metal waste later was removed from the tanks and reprocessed for uranium recovery, generating a uranium recovery waste stream (also designated as a TBP waste stream). Essentially all the chemicals and the radionuclides except uranium present in the recovered metal waste were returned to the tanks in the TBP waste stream. While a significant quantity of TBP waste remains in some BY tanks, a substantial fraction of TBP waste was intentionally discharged to the BY and BC cribs. (See Appendix A and the Appendix A table titled "Appendix 1: Intentional Release Quantities.") Before TBP waste was discharged to the soil column, it was treated with ferrocyanide and Ni(II) to form a mixed salt precipitate of cesium, sodium, nickel, and ferrocyanide. A summary of TBP analyses is provided in Appendix A.

(See the table titled "Appendix 6: Scavenged TBP Waste Disposal to BY Cribs." Note that uranium concentration values are 100,000 times smaller than those listed.)

Because tank waste components were found in the groundwater near the BX trenches and BY cribs, discharge of tank waste to the soil column was stopped (Williams 1999). Subsequently, an ITS program was initiated to reduce liquid volumes in tanks containing TBP waste by heating waste in the tanks, collecting the condensate, then discharging the condensate to the ground (see Section 2.1.2). Extensive modifications to the waste transfer system were required to implement the ITS program and a number of near-surface transfer line leaks were reported during its operation. Chemical analyses of ITS waste have not been found.

The final type of waste associated with a major processing operation that is stored in some of the B, BX, and BY tanks was derived from B Plant $^{90}Sr/^{137}Cs$ recovery operations (see Section 2.1.2). None of this waste was deliberately discharged to the soil column. A distinguishing characteristic of this waste is the use of organic complexing agents to remove ^{137}Cs and ^{90}Sr. Organic complexing agents in this waste could react with radionuclide contaminants and alter the movement of metal ions in the soil column once waste has leaked. Thus, when considering the current radionuclide distribution in the soil column resulting from leaking tanks containing this waste type, the role of organic complexing agents in past radionuclide migration must be evaluated. A likely signature of this waste in the soil column is the presence of ^{90}Sr, which has been postulated from spectral gamma logging data analysis to be present in drywells surrounding some of the B farm tanks that have been reported as probable leakers. One might expect to see similarities in the mobility of B Plant waste lost to the soil column in the B-BX-BY WMA and the waste components lost during the major leak event associated with tank T-106 in 1973 (Jones et al. 1999). It also is important to appreciate that the class of organic compounds lost in leak events containing B Plant high-level waste would not readily be detected using regulatory-dictated gas chromatography/mass spectrometry organic analysis methods (Jones 1999). No additional analyses of this waste have been found.

3.3 B-BX-BY WMA TANK LEAK EVENTS

Hanlon (1999) lists 10 tanks in the B tank farm, 5 tanks in the BX tank farm, and 5 tanks in the BY tank farm as "Confirmed or Assumed Leakers." Estimated leak volumes vary from 70,000 gal[1] to 2,000 gal in the 23 m (75-ft)-diameter tanks. No estimated leak volume is provided for nine of the tanks listed in Hanlon (1999). The lack of an estimated leak volume in Hanlon (1999) tends to indicate that evidence used to designate the tank as a leaker is equivocal.

Information currently available was reviewed to ascertain potential leak events in this WMA that require additional field characterization. In addition to the spectral gamma logging data (see Section 3.1), waste transfer records (Agnew 1997) and various tank leak documents were reviewed to develop the list of tanks that most likely actually leaked. The rationale for this approach is to identify locations where subsurface characterization likely would be most

[1] Tank capacities and leak volumes have historically been measured in gallons and are still being reported in gallons in the Hanlon reports. Therefore, tank capacities and leak volumes will be measured in gallons in this document.

successful. For example, a number of tanks are listed as confirmed or suspected leakers by Hanlon (1999), but neither the waste level data nor the gamma logging data support the leak designation. These tanks would obviously be poor candidates for field investigations. The goal is to identify investigation sites that will maximize the return on investment.

In addition, an attempt was made to distinguish between probable transfer line leaks and leaks that more likely came from the tanks. As shown by Figure 2-1, the cascade lines between the tanks were about 20 ft below the surface. Waste transfer lines installed after the tanks were constructed would have been closer to the surface. Thus, if gamma contamination appears between the surface and a depth of approximately 9 m (30 ft), it likely would have come from a waste transfer, cascade line, or a tank overfill. Gamma activity appearing at the base of the tank could have originated from a tank leak or could have puddled at the base of the original excavation after migrating from a waste transfer or cascade line leak.

3.3.1 B Tank Farm Tanks

Seven of the twelve 23 m (75-ft)-diameter tanks in the B tank farm are listed as being confirmed or suspected of having leaked (Hanlon 1999). Leak volume estimates for two of these tanks (B-107 and B-110) were based on tank waste level measurements. Reliable leak volume estimates are unavailable for the other tanks (B-101, -103, -105, -111, and –112) (Nelson and Ohl 1999, Baumhardt 1989).

Tank B-101 was included on the suspected leak list based on gamma activity in drywells 20-01-01 and 20-01-06 (Nelson and Ohl 1999). Review of the drywell logs shows only a ^{137}Cs peak of less than 100 pCi/g at about 13 m (42 ft) below the surface. Waste transfer records are inconclusive. This evidence does not indicate that tank B-101 is a leaker. (See Section 3.3.4 for further discussion.)

Tank B-103 was included on the suspected leak list based on gamma activity in drywells 20-03-03 and 20-03-06 (Nelson and Ohl 1999). Neither drywell log indicates any contamination above 1 pCi/g below 9 m (30 ft). This evidence does not indicate that tank B-103 is a leaker. (See Section 3.3.4 for further discussion.)

Tank B-105 was classified as an assumed leaker in 1978 based on gamma activity in drywells 20-05-06 and 20-06-06. Both drywells have narrow bands of activity at about 15 m (50 ft) deep. Tank B-107 was designated as an assumed leaker based on liquid level decreases. Decreases in liquid levels between 1963 and 1969 indicate that 8,000 gal were lost from the tank. Drywell 20-07-02 exhibits ^{137}Cs activity in the region of 11 m to 18 m (35 to 60 ft) at levels up to 1,000 pCi/g. Drywells 20-10-02 and 20-07-11 appear to have ^{90}Sr activity in the region between 21 m and 24 m (70 and 80 ft). The ^{90}Sr probably came from a leak between tanks B-110 and B-111.

Tank B-110 is considered a confirmed leaker based on decreases in liquid level measurements (Nelson and Ohl 1999). The leak volume is assumed to be 10,000 gal. Drywell 20-10-12 has gamma activity beginning at 6 m (20 ft) that saturates the detector from 8 m to 30 m (25 to 100 ft). Between 30 m and 34 m (100 and 110 ft), concentrations of both ^{137}C and ^{235}U are reported to be about 1,000 pCi/g. As already noted, drywell 20-10-02 has an apparent band of ^{90}Sr from 21 m to 24 m (70 to 80 ft). The waste transfer records suggest the loss of materials from tank B-110 could have been caused by an overfill rather than a tank leak.

The gamma activity profile on drywell 20-10-12 supports the hypothesis of a tank overfill. Tank B-111 was listed as an assumed leaker based on gamma activity in drywells 20-11-09 and 20-12-06. Based on the spectral gamma logging data, neither drywell indicates any tank leakage. The tank liquid level measurements also do not indicate leakage from tank B-111. Tank B-112 was characterized as being of "Questionable Integrity" in 1978 based on unexplained gamma activity in drywells 20-12-03 and 20-12-06. However, the spectral gamma logging data from these drywells do not indicate a tank leak. Tank liquid level measurements also do not indicate a tank leak.

3.3.2 BX Tank Farm Tanks

Hanlon (1999) includes estimated leak volumes for only two of the five tanks listed as confirmed or assumed leakers. The tank BX-102 leak volume is reported to be approximately 70,000 gal (Womack and Larkin 1971) and the tank BX-108 leak volume is reported as 2,500 gal. Reliable estimates of leak volumes are not available for tanks BX-101, -110, and -111 (Nelson and Ohl 1999 and Baumhardt 1989).

3.3.2.1 Tanks BX-101 and BX-102. These tanks are discussed together because current evidence suggests that neither tank actually leaked, but that gamma-logging data from drywells near both tanks were affected by an overfill of tank BX-102 that took place in 1951. Tank BX-102 was declared a leaker based on an extensive investigation conducted in 1970 and 1971 (Womack and Larkin 1971). This investigation was triggered by increasing gross gamma being measured in a drywell located about 30 m (100 ft) east-northeast of the tank. As part of this investigation, 19 new drywells were installed near tank BX-102 and the tank supernatant liquids were analyzed. One well (currently numbered 21-02-04) was drilled to groundwater near tank BX-102 and soil analyses were performed on many core samples. Cs-137 was found at levels up to 100 μCi/g in these soil samples. Gross gamma logging of the drywell defined a plume extending to the east from tank BX-102. Based on the estimated plume volume, a 30-percent soil porosity, and ^{137}Cs levels measured in tank waste in 1970, the leak volume was estimated to be 70,000 gal. Womack and Larkin (1971) note that, in 1951, a 90,000-gal transfer line leaked between tanks BX-102 and BX-103. Based on a 1960 internal letter, the waste-type for the 1951 transfer line leak was identified as first-cycle $BiPO_4$ waste.

The 70,000-gal leak volume for tank BX-102 developed by Womack and Larkin (1971) is currently listed by Hanlon (1999). However, the spectral gamma data reported by MACTEC-ERS in 1998 for the series of drywells used in the Womack and Larkin (1971) study reveal the primary source of the gamma radiation, which the 1971 study assumed to be ^{137}Cs, actually is ^{238}U and ^{235}U. In fact, the high level of ^{238}U and ^{235}U is a "fingerprint" for metal waste coming from the $BiPO_4$ process. The metal waste contained approximately 0.5 lb/gal of uranium plus approximately 90 percent of the fission products (Anderson 1990).

Because the three-tank cascade, BX-101 through BX-103, was filled with metal waste from its initial filling in 1948 until it was sluiced out in 1953 and 1954 (Anderson 1990), assigning the 1951 transfer line leak as first cycle waste was, without question, incorrect. Any loss of tank waste in this cascade would have clearly involved metal waste, not first cycle waste. The significance here is that first cycle waste would have been far more dilute than metal waste (Anderson 1990). Further investigation turned up a declassified section of the March 1951 Hanford Works Monthly (production) Report (HW-20438-Del) that describes overfilling

tank BX-102 with metal waste and the estimated loss of 91,600 gal of metal waste containing 20411.7 kg (22.5 tons) of uranium, apparently through a faulty spare inlet port. The 1951 report was declassified in 1992. Had Womack and Larkin had access to the 1951 report, they would likely have questioned the fate of the 20411.7 kg (22.5 tons) of uranium lost to the vadose zone in the vicinity of tank BX-102 and may have explained the 1971 gamma logging data differently.

3.3.2.2 Tanks BX-108, BX-110, and BX-111. Hanlon (1999) lists these three tanks as confirmed or suspected leakers, but includes an estimated leak volume only for tank BX-108. The 2,500-gal leak estimate for tank BX-108 is based on a reported in-tank liquid level decrease of 2.2 cm (0.9 in.) over 9 months and 300-count-per-second gamma activity at the 14 m (45-ft) level in drywell 21-08-06 (Burton 1974). Analysis of the historical gamma logging data for this drywell indicates the activity was ^{106}Ru based on decay rates (Myers 1999a). Thus, the gamma activity detected in drywell 21-08-06 would likely have been the edge of a tank waste plume. In drywell 21-08-07, ^{137}Cs contamination at the surface is 10 pCi/g, a 1000 pCi/g peak occurs at 1.5 m (5 ft), and a narrow band of ^{137}Cs contamination high enough to saturate the detector occurs at 2.4 m (8 ft). Cs-137 and ^{60}Co are detected to a level of about 21 m (70 ft). Drywell 21-11-03 has a narrow band of ^{137}Cs contamination at 13 m (42 ft). This band is concentrated enough to saturate the detector. Other drywells around this tank have ^{137}Cs surface contamination at levels of from 1 to 100 pCi/g.

Sometime in the 1970's, tank BX-110 was listed as an assumed leaker based on increased radiation levels in some surrounding drywells. Documentation of the leak designation currently is unavailable. Drywell 21-10-01 shows ^{137}Cs contamination of 10 pCi/g at the surface and a sharp spike of approximately 100 pCi/g at 12 m (40 ft). Drywell 21-10-03 has a ^{137}Cs contamination level of 5,000 pCi/g at the surface and contamination that saturates the detector at a depth between 2.4 m and 12 m (8 and 40 ft). Cs-137 contamination at concentrations up to 5,000 pCi/g extend down to a depth of 27 m (90 ft) in this drywell (MACTEC-ERS).

The gamma contamination in drywell 21-10-05 is unusual and suggests an origin other than tank BX-110. The usual 5 to 50 pCi/g of ^{137}Cs contamination occurs in the first 6 m (15 ft) of the borehole, a ^{137}Cs zone between 11 m and 15 m (37 and 48 ft) saturates the gamma detector, and ^{137}Cs contamination of approximately 5,000 pCi/g occurs between 15 m and 20 m (48 and 65 ft). Interestingly, the zone between 15 m and 20 m (48 and 65 ft) includes ^{235}U contamination at levels of 50 to 80 pCi/g. The ^{235}U is a fingerprint for metal waste. If ^{235}U is present in this zone, ^{238}U also would be present at two orders of magnitude higher concentrations (based on natural uranium isotopic ratios). The determination of ^{238}U may have been masked by the high levels of ^{137}Cs in this zone.

The presence of a metal waste signature in drywell 21-10-05 is unexpected because this tank was not used to store metal waste. The tanks in the BX-110-BX-111-BX-112 sequence were used to store $BiPO_4$ first cycle waste, while metal waste was stored and recovered from tanks in the B-BX-BY WMA (Anderson 1990 and Agnew 1997). However, sluiced metal waste was pumped through pipelines running west of tank BX-110 and east of tank BX-107. In addition, the BXR vault is located about 62 m (200 ft) south of tank BX-110. Because drywell 21-10-07 lies between the pipelines west of tank BX-110 and is essentially uncontaminated below the first couple of feet, the pipeline west of tank BX-110 is unlikely to have been the source of the metal waste. However, the metal waste contamination could have come from the metal waste transfer lines east of tank BX-107. Drywell 21-07-06 is highly

contaminated at tank bottom depth and below and is located between drywell 21-10-05 and the transfer pipes east of tank BX-107. Another source of metal waste contamination could be associated with a 22,000-gal waste transfer between the BXR vault and tank BX-110 in 1961. The 22,000 gal of waste would have been only about 5 percent of the tank waste volume. Thus, it would have been a minor component of any leaked materials. However, losses of materials during transfer might explain the metal waste observed in the drywell.

Tank BX-111 was listed as an assumed leaker in 1978 because of increased activity in the surrounding drywells (Nelson and Ohl 1999). Drywells 21-11-03 and 21-11-04 near tank BX-111 have narrow bands of contamination (approximately [0.6 m] 2 ft) at the 12 m (40-ft) level that saturate the gamma detector. No other drywells around this tank exhibit contamination profiles that would indicate a tank leak.

3.3.2.3 Other Contaminated Drywells in the BX Tank Farm. Drywell 21-03-12 has a 1.2 m (4-ft) zone beginning at 6 m (21 ft) that saturates the gamma detector. This contamination probably came from a transfer line leak, not from the tank. Drywell 21-06-05 has contamination from 11 m to 17 m (36 to 55 ft) that clearly has a metal waste signature. Metal waste was stored in this tank from 1948 through 1955. Had the tank been leaking during that period, additional liquid loss would have been expected over the next 20 years the tank was used for storing various waste types. Thus, the metal waste probably was lost from a transfer line or from a brief tank overfill event.

3.3.3 BY Tank Farm Tanks

Although five tanks in the BY tank farm are listed as confirmed or assumed leakers (Hanlon 1999), the gamma logging reports and waste transfer records contain little data to support including the tanks on a tank leaker list. Unfortunately, none of the primary documents are available that detail the rationale for including these tanks on the tank leaker list.

Many of the drywells in the BY tank farm contain widespread surface contamination in the range of 100 pCi/g of ^{137}Cs. In most cases, the ^{137}Cs levels decrease with depth. Cobalt-60 is frequently found from about the 12 m (40-ft) level to the bottom of the drywell. Cesium-137 activity sufficiently high to saturate the gamma detector in the first 1.2 m (6 ft) is reported in drywells 22-00-01, 22-05-04, 22-08-02, and 22-12-03. Cesium-137 activity below 1.2 m (6 ft) that is sufficiently high to saturate the gamma detector is reported only for drywell 22-03-05 in the zone between 7 m and 14 m [24 and 47 ft]). Cesium-137 peaks of 100 pCi/g in the 14 m to 15 m (45- to 50-ft) depth are reported for drywells 22-02-01 and 22-03-06. Because ^{235}U and ^{238}U were not reported in any spectral gamma logging data from any drywells in the BY tank farm, none of the tank waste lost to the soil column involved metal waste. The common occurrence of ^{60}Co in drywells across this tank farm would suggest most of the tank waste lost originated from the uranium recovery process. This was the type of waste produced in the ITS process and ^{60}Co is known to be reasonably mobile in this form.

3.3.4 Summary of Leak Information from B-BX-BY WMA

The leak information for the seventeen 23 m (75-ft)-diameter tanks in the B-BX-BY WMA listed as confirmed or assumed leakers is summarized in Table 3-2. The two strongest indicators of leak events are historical liquid level records for individual tanks and gamma logging data of contamination around the tanks. Historical records of liquid level changes and liquid transfer operations for individual tanks show liquid losses unaccounted for by waste transfer operations. High gamma readings (generally at concentration levels above spectral gamma logging tool detection limits) are the consequence of interactions between tank fluids and the soil. Given the routine ^{137}Cs concentration estimates in tank fluids (> 0.01 Ci/L according to Agnew 1997) and the tendency of ^{137}Cs to sorb and therefore concentrate on Hanford Site soils, soil contamination levels well above 1000 pCi/g must result somewhere in the vicinity of the tank fluids-soil interaction. In cases where gamma readings of 100 pCi/g or less below 8 m (25 ft) are observed around a tank, release of fluids from the tank is not plausible at the drywell location. When all drywells around a tank show these low ^{137}Cs concentrations, the likelihood of leakage from that tank is reduced further. When neither liquid level records nor gamma contamination indicate leakage, we can assume that leakage either did not occur or occurred at such a low level as to be an inconsequential source of contamination.

As Table 3-2 indicates, an important conclusion from this review is that evidence of non-leakage exists for several tanks assumed to be leakers. Consequently, for purposes of making characterization decisions, these tanks are not considered to be sources of current vadose zone contamination.

Table 3-2. Tank Leak Information Summary.

Tank Number	Liquid levels indicate leak?	Gamma logging data indicate leak?	Assumed leak date
B-101	No	No	Likely no leak
B-103	No	No	Likely no leak
B-105	No	Yes	1978
B-107	Yes	Yes	1969
B-110	Yes	Yes	1968??
B-111	No	No	Likely no leak
B-112	No	No	Likely no leak
BX-101	No	No	Likely no leak
BX-102	Yes	Yes	1951
BX-108	Yes	Yes	1974
BX-110	No	Yes	1970
BX-111	No	Yes	1978 and 1993
BY-103	No	Yes	1973
BY-105	No	No	Likely no leak
BY-106	No	No	Likely no leak
BY-107	No	No	Likely no leak
BY-108	No	No	Likely no leak

3.4 INTENTIONAL LIQUID WASTE DISPOSALS TO SURROUNDING CRIBS AND TRENCHES

Section 2.1.2 and Appendix A summarize the history of intentional disposals to cribs, trenches, and wells surrounding the B-BX-BY WMA. These facilities received some of the largest quantities of liquid waste ever discharged at the Hanford Site. Most of the more contaminated waste (first cycle and TBP waste) was discharged before 1956. The most recent large discharge of ITS condensate occurred from 1968 to 1973 at tank 216-B-57. Given the high volume of discharged liquid, particularly to the BY cribs and BX trenches, a saturated column from the surface to the water table likely formed during discharge. This column facilitated rapid transfer of mobile contaminants to the unconfined aquifer. Also, drainage of the soil column following cessation of discharge is likely to be largely complete. Thus, mobile constituents in the drainage fluid also would have been discharged into the unconfined aquifer. This scenario is supported by the characterization of soils underlying the BY cribs (DOE/RL 1993) where low moisture content and contaminant concentrations were measured.

Estimates and measurements of radionuclide and chemical constituents discharged to these cribs, trenches, and wells are limited. Inventory estimates have not been found for contaminants discharged to cribs 216-B-7A, 216-B-7B, 216-B-8, and reverse wells 216-B-11A, and 216-B-11B. Diedeker (1999) provides a partial list of radionuclide inventories, including ^{90}Sr, ^{106}Ru, ^{137}Cs, and total uranium, decayed to December 31, 1998, for the BY cribs and BX trenches. DOE/RL (1993) provides a similar list, including estimates of primary chemicals (nitrate, phosphate, and sodium), for the BY cribs. Comparing estimates of BY crib radionuclide inventories shows fair agreement between the two sources. Diedeker (1999) lists estimates of 4,456 Ci for total ^{90}Sr and 1,374 Ci for total ^{137}Cs; DOE/RL (1993) lists estimates of 5,500 Ci for total ^{90}Sr and 1,920 Ci total ^{137}Cs. Both sources estimate a total uranium discharge of 0.18 Ci. Diedeker (1999) estimates discharged inventories of 1,347 Ci of ^{90}Sr, 2,319 Ci of ^{137}Cs, and 0.27 Ci of total uranium in the BX trenches.

Appendix B of Agnew (1997) provides an additional evaluation and a more complete list of estimated radionuclide and chemical concentrations arranged by waste stream. These estimates are based on process knowledge. Given that disposals were entirely TBP waste in BY cribs, and first cycle waste in BX trenches except for trench 216-B-43, which received TBP waste, estimates of the other chemicals and radionuclides can be calculated using Agnew's concentrations and volume discharge records for these facilities. For example, ^{99}Tc inventory estimates for discharges into BY cribs and BX trenches are about 155 and 20 Ci, respectively, assuming TBP and first cycle waste concentrations of 4.9×10^{-6} and 1.2×10^{-6} Ci/L, respectively.

3.5 GROUNDWATER CONTAMINANT INFORMATION

This section covers the current state of contamination surrounding the B-BX-BY WMA, including historic constituent trends that depict the temporal and spatial distribution of contaminants. Several distinct suites of contaminants are recognized, based on spatial relationships and on identifying ratios of cocontaminants. Given the complicated history of waste discharges to the subsurface in the last 50 years combined with artificial reversals in the natural flow direction and the ambiguities in the current flow direction, identifying sources is difficult. Nonetheless, with careful groundwater monitoring and data analysis, possible sources for the observed contamination are tentatively identified.

The WMA boundaries and monitoring well locations, along with associated tanks, diversion boxes, and sites of major unplanned waste releases are shown in Figure 3-1.

3.5.1 Background

Since the early 1950s, groundwater monitoring has been conducted near the B-BX-BY WMA in accordance with the *Atomic Energy Act of 1954*. Following the 1989 signing of the Tri-Party Agreement, the single-shell tank farms that make up this WMA were designated as hazardous waste units and are regulated under RCRA and Washington's "Hazardous Waste Management Act" (RCW 70.105). As such, these facilities are subject to the interim-status regulations in Title 40 *Code of Federal Regulations* (CFR) Part 265 (Subpart F) and *Washington Administrative Code* (WAC) 173-303.

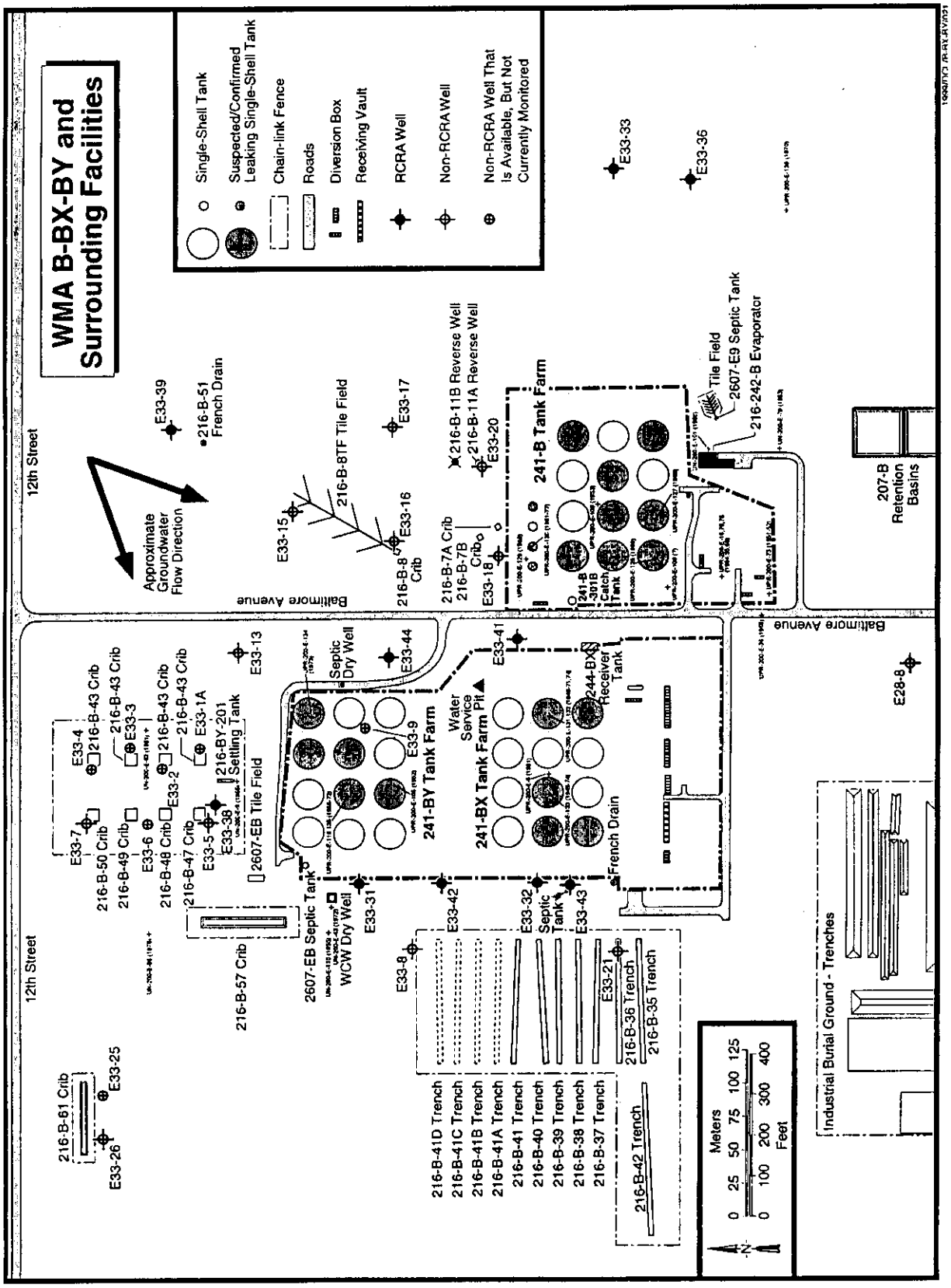
In 1991, a system of RCRA-compliant wells was installed around this WMA to monitor the quality of the groundwater (Jensen et al. 1989, Caggiano and Goodwin 1991). In 1996, based on conductivity values that were elevated above the critical mean of 365.7 μmhos/cm in downgradient well 299-E33-32, the WMA was placed in a groundwater quality assessment program as required by the regulations (Caggiano 1996). The monitoring frequency was increased from semiannually to quarterly. During 1997, nitrate and ^{99}Tc were observed above the drinking water standards (DWS) of 45,000 μg/L and 900 pCi/L, respectively, in well 299-E33-41, located between the B and BX tank farms. Based on a first-determination investigation, waste from the WMA was concluded to have entered the groundwater and was observed in this well (Narbutovskih 1998). For a more complete discourse on the contamination events observed at well 299-E33-41, see Narbutovskih (1998). Although nitrate and ^{99}Tc were rising in the groundwater along the western side of the WMA, it was concluded in the first-determination assessment that identifying the sources at well 299-E33-32 was determined to not yet be possible. A further determination is being conducted to determine the rate and extent of groundwater contamination at this WMA.

The historic and recent RCRA groundwater data for this site are stored in the Hanford Environmental Information System (HEIS) and are available electronically as needed. The RCRA data are released on a floppy disk annually in the Hanford Site groundwater monitoring report (e.g., Hartman 1999). The RCRA data are collected in accordance with established quality assurance and quality control procedures (EPA 1986). These documents are described in Hartman (1999).

3.5.2 Contaminants

Although the primary inorganic constituents in tank waste at the B-BX-BY WMA include nitrate, sulfate, ^{137}Cs, ^{90}Sr, ^{99}Tc, aluminum, cyanide, uranium, and other heavy metals, most are not mobile. The main tank constituents known to be mobile and used for tracking tank-related waste are nitrate and associated anions, ^{99}Tc as TcO_4^-, and uranium. Groundwater samples also are analyzed for ^{60}Co, which can be mobile in the presence of the ferrocyanide anion.

Figure 3-1. Location Plan of the B-BX-BY WMA.



The following discussion centers on constituents used to track contamination moving through the WMA and identify suites of contamination that, most likely, have different source histories. Discussing suites of constituents that appear centered on three different wells is more constructive than discussing each contaminant species separately.

3.5.2.1 Well 299-E33-7. The highest recent values of ^{99}Tc (7,030 pCi/L) are observed in the northern area of the BY cribs at well 299-E33-7. The DWS is 900 pCi/L. Technetium-99, however, has risen in wells farther to the south in the BY cribs and along the western side of the WMA (Figure 3-2). The elevated nitrate apparently migrating with the ^{99}Tc also was observed farther to the west in wells at the northeast corner of WMA LLBG 1 (Figure 3-3). Nitrate concentrations in all the wells noted in Figures 3-2 and 3-3 are above the 45,000-µg/L DWS. The July 1999 value in well 299-E33-7 was 336,879 µg/L. Analyses of groundwater from the wells at WMA LLBG 1 indicate that ^{99}Tc also is rising and appears to be moving southwestward; ^{99}Tc recently was detected in well 299-E33-35 (Figure 3-4). High values of tritium (maximum of 10,500 pCi/L at well 299-E33-7) track with the elevated ^{99}Tc.

With the recent data collected for the RCRA assessment at the B-BX-BY WMA, ^{99}Tc and nitrate appear to have been rising since the early 1990s. This observation is consistent with the recent analysis of the groundwater-flow direction from the northeast to the southwest (see Section 2.4.2). This plume movement implies that the source is the original BY crib plume moving back through the area with the lowering of the water table farther to the east. Nitrate, along with chloride, sulfate, and associated cations, apparently is causing the elevated conductivity value first observed in well 299-E33-32 in 1996.

Figure 3-2. Historic Trends of ^{99}Tc at the BY Cribs and in Wells Farther South Along the West Side of the B-BX-BY WMA.

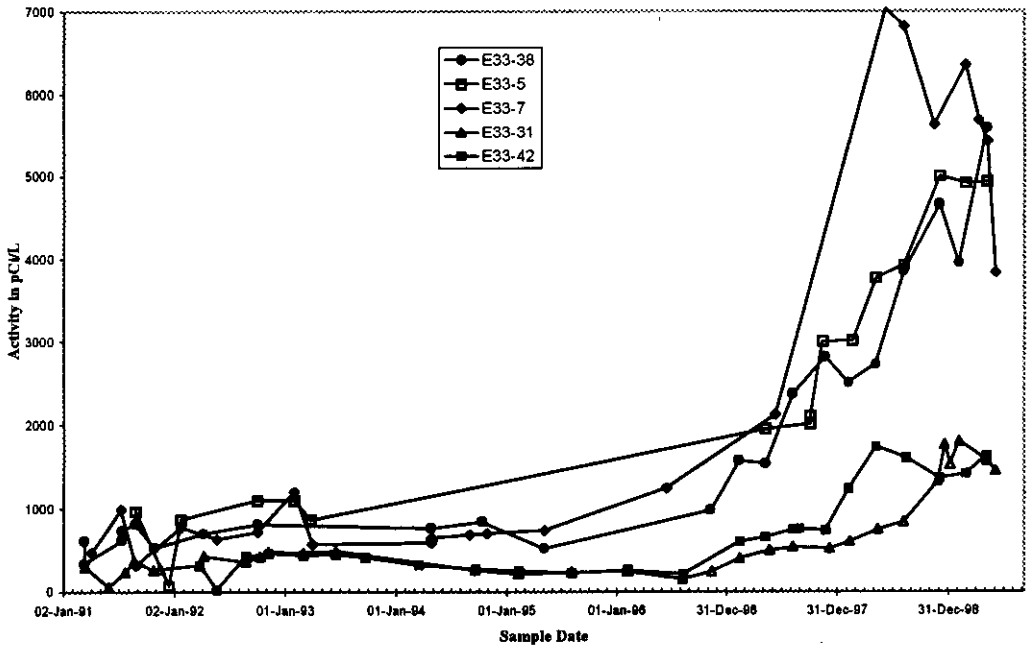


Figure 3-3. Historic Trends of Nitrate in the Local Region of the BY Cribs and the Northeastern Corner of WMA LLBG 1 West of the B-BX-BY WMA.

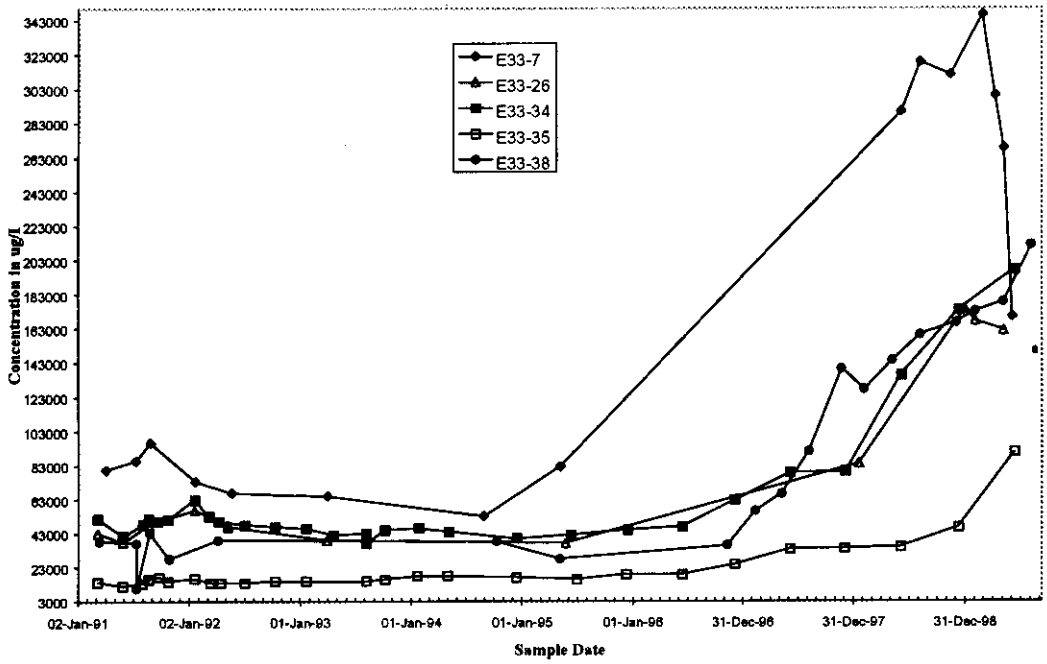
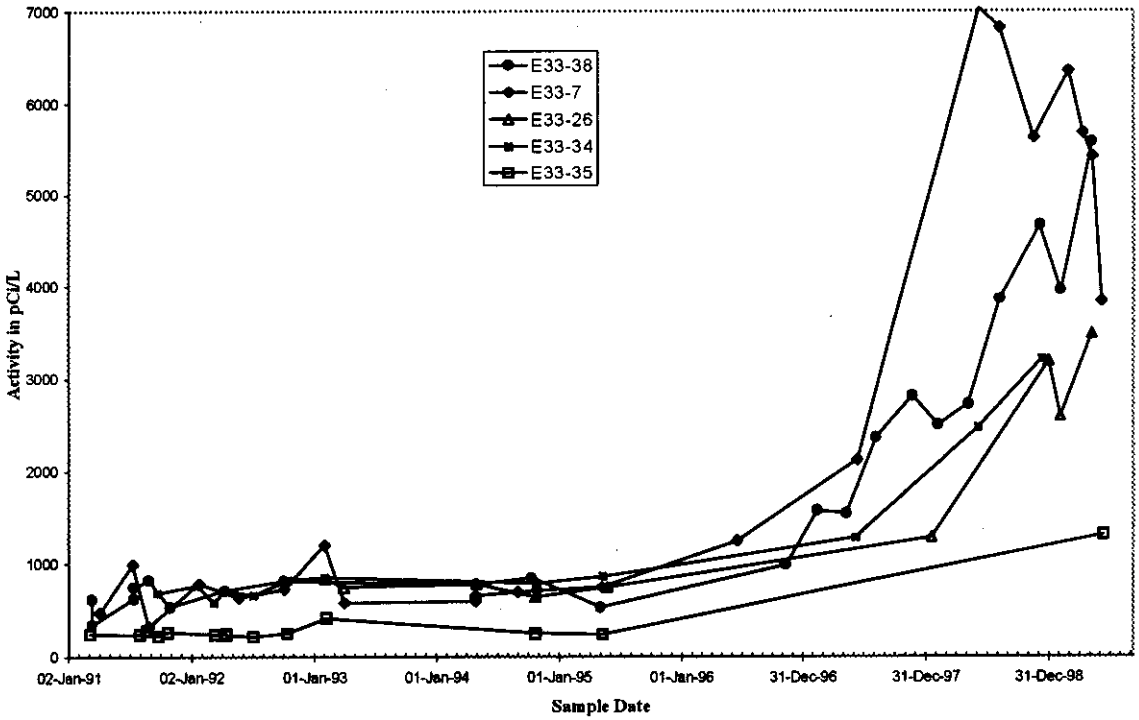


Figure 3-4. Historic Trends of ^{99}Tc at the BY Cribs and in Wells Farther to the West, Indicating Northeast to West-Southwest Plume Movement



The groundwater beneath the BY cribs in wells 299-E33-7, -38 and -5 also has shown ^{60}Co and cyanide. The highest values, found at well 299-E33-7, were 66 pCi/L for ^{60}Co and 347 µg/L for cyanide in June 1998. The DWS for ^{60}Co and cyanide is 100 pCi/L and 200 µg/L, respectively. Cyanide and, possibly, ^{60}Co also are found southeast of the BY cribs in samples from well 299-E33-13. Contamination observed in well 299-E33-13 has recently assumed a character similar to that at well 299-E33-7. Cyanide and ^{60}Co have not yet been observed in other wells in the area. Consequently, whether these constituents are moving with the nitrate, ^{99}Tc, and tritium or are entering the groundwater from the vadose zone is not yet clear.

3.5.2.2 Well 299-E33-16. The main characteristic of contamination observed in the groundwater at this site is the extremely high nitrate value (near 500,000 µg/L) (Figure 3-5). The nitrate is associated with ^{99}Tc, which is above the DWS at about 2,000 pCi/L in June 1999. Chromium is elevated at 53.5 µg/L, but is still below the 100 µg/L DWS. Nitrate in quantities above the DWS also is observed at surrounding wells 299-E33-15, -17, and -20. However, ^{99}Tc and chromium are not elevated in the groundwater at these wells, suggesting that the contamination at well 299-E33-16 is localized.

3.5.2.3 Well 299-E33-44. This well was constructed in 1998 to fill a gap between wells 299-E33-41, 299-E33-13, and 299-E33-38. High levels of ^{99}Tc (12,000 pCi/L in August 1997) and uranium (maximum of 81 µg/L in November 1998) were observed at well 299-E33-41 and elevated nitrate, ^{99}Tc, and uranium were seen in wells 299-E33-13 and -38. The relationship between the ^{99}Tc and uranium in well 299-E33-41 is shown in Figure 3-6. Similar increases in chloride and sulfate were found to correlate with the high-frequency pulses from ^{99}Tc. As can be seen, the associated uranium traveled through the local area more slowly.

Initial groundwater samples from well 299-E33-44, collected in October 1999, revealed that, not only are ^{99}Tc and nitrate above the DWS (4,480 pCi/L and 95,176 µg/L, respectively), but the highest levels of uranium in the area are found here (see Figure 3-6). The maximum concentration of 350 µg/L for uranium was found in April 1999. Unlike the ^{99}Tc and nitrate observed to the north, the groundwater in this locale contains neither cyanide nor ^{60}Co in detectable quantities. Also, relatively high levels of nitrite (400 to 600 µg/L) were found in the groundwater samples at this site. A check for coliform was negative. Efforts are currently under way to sample well 299-E33-9 inside the 241-BY tank farm to ascertain whether the nitrite is confined to well 299-E33-44 or if a small plume is located under this WMA.

3.5.2.2 Contaminant Ratios. One of the best diagnostic tools for identifying different contaminant plumes in the groundwater surrounding this WMA is the ratio of nitrate to ^{99}Tc. Tank-related sources might be expected to have low ratios because of the large concentrations of ^{99}Tc found in the tanks today (Kupfer et al. 1997). For example, the ratio of nitrate to ^{99}Tc for the pulses of contamination shown in Figure 3-6 are about 4. This number is low compared to the background values, which are in the thousands.

Nitrate-to-^{99}Tc ratios for data collected during the second quarter of 1999 are mapped in Figure 3-7. For contamination associated with well 299-E33-7, ratios generally range from 40 to 50. Ratios within this range cover the BY cribs and the west side of the WMA, and extend to the west at wells 299-E33-26, -34, and -35. Because nitrate and ^{99}Tc are increasing at wells 299-E33-28, -32, and -43, the region displaying this signature is expected to expand.

Figure 3-5. Historic Trend Plots of Nitrate Concentrations and ^{99}Tc Activities at Well 299-E33-16.

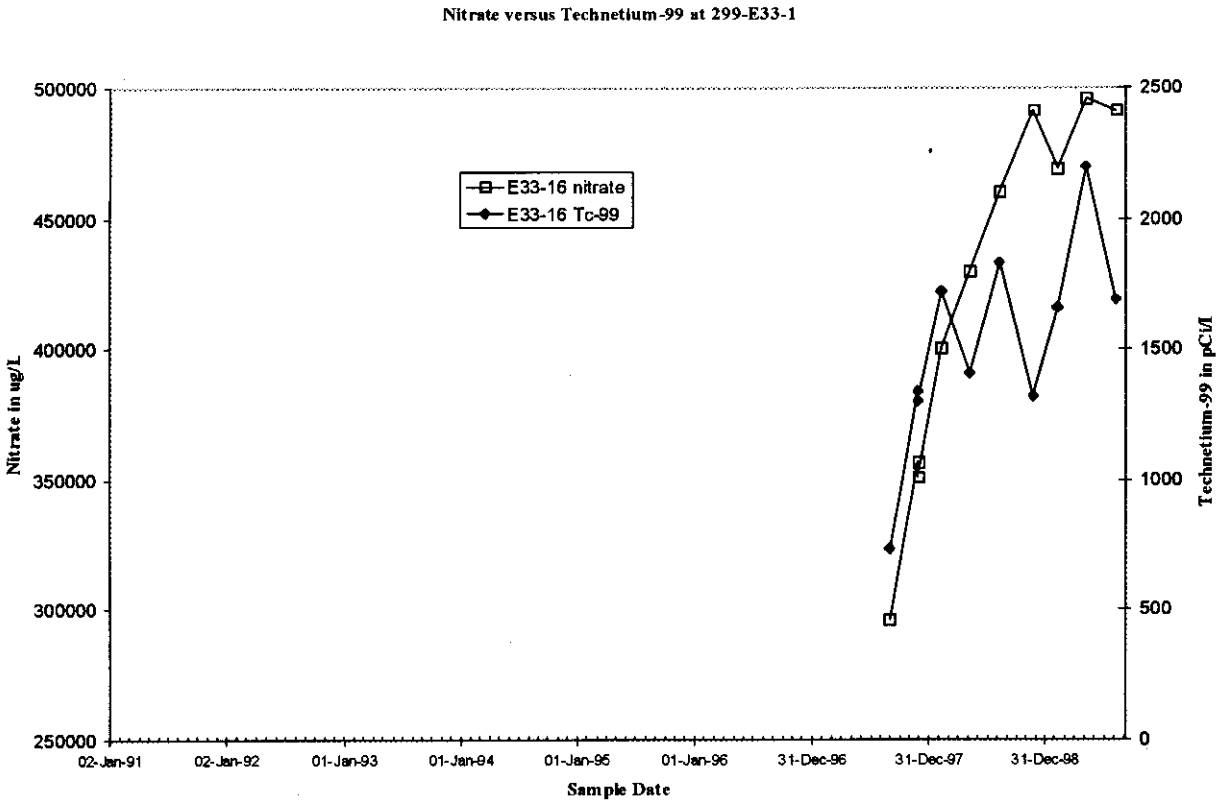


Figure 3-6. Historic Trends of ^{99}Tc and Uranium for Well 299-E33-41.

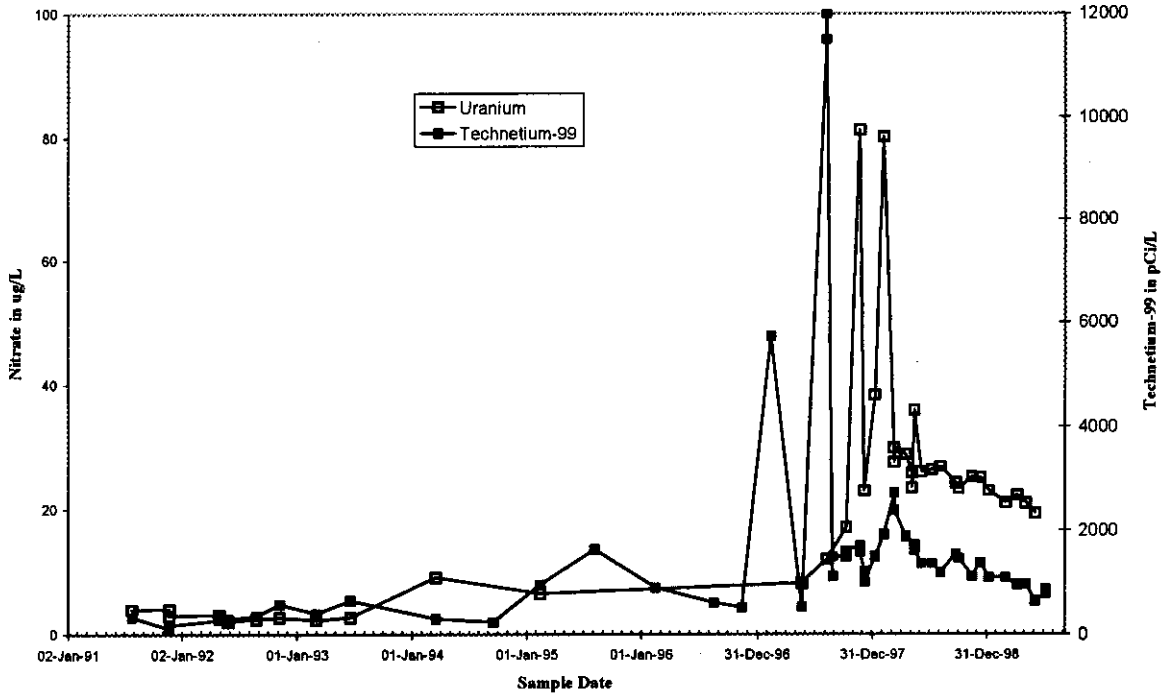
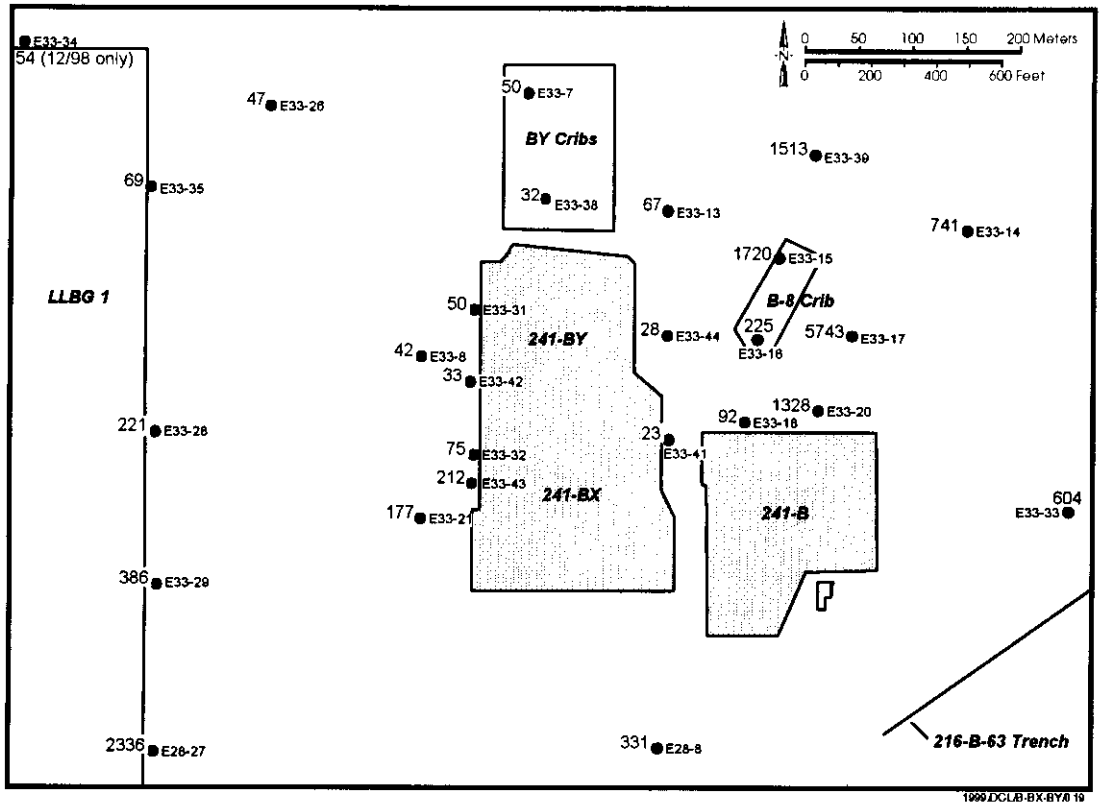


Figure 3-7. Ratio of Nitrate to ^{99}Tc (Second Quarter).



During the period of northward movement, probably before the early 1990's, the highest concentrations of ^{99}Tc and nitrate were found in well 699-50-53A, located north-northeast of the study area. The nitrate-to-^{99}Tc ratio from this well during the early 1990's is 42, for a ^{99}Tc value of 17,000 pCi/L and 716,000 μg/L of nitrate. This ratio is similar to that of the contamination currently moving through the northern part of this WMA.

The nitrate-to-^{99}Tc ratio at well 299-E33-16 is above 200 because of the very high levels of nitrate with lower ^{99}Tc values, less than half that observed at wells 299-E33-7 or -44. As can be seen in Figure 3-7, none of the surrounding wells have a similar ratio. Wells immediately to the north, east, and south have high nitrate values, but do not have ^{99}Tc above the DWS, which results in much higher ratios of nitrate to ^{99}Tc than at wells 299-E33-7 or -44. The contamination observed at this well appears to have a limited spatial extent. At least part of the aquifer at this site may be locally isolated by a depression on the basalt surface. The relief on the top of the basalt can be as much as 4.3 m (14 ft), which is more than the about 2.4 m (8-ft) thickness of the aquifer at this well. If the lower part of the aquifer is locally in a small depression, the contamination observed in the groundwater may be residual from liquid waste discharged to the 216-B-8 crib, which was used from the late 1940s to about 1952.

Finally, the ratios at wells 299-E33-41 and -44 are noticeably lower than at wells in the surrounding area. For example, the nitrate and ^{99}Tc levels at well 299-E33-41 are significantly low; both currently are below the DWS. If a groundwater sample can be collected from well 299-E33-9, located west of well 299-E33-44 but within the tank farm boundaries, further

conclusions may be possible concerning the source of this groundwater contamination at well 299-E33-44.

3.5.3 Correlation with Possible Sources

Contamination discharged to the ground at the BY cribs appears to be migrating back from the north in a southwesterly direction, affecting the groundwater under the northwestern part of the B-BX-BY WMA. This plume, consisting of nitrate, ^{99}Tc, and tritium, is being monitored as it moves from the BY and BX tank farms into the northeastern corner of the LLBG 1 WMA. Currently, whether the cyanide and ^{60}Co associated with the original plume are moving through the area is unclear. Although these contaminants are observed in the groundwater under the BY cribs, as of May 1999, they have not been detected farther to the west or south except in well 299-E33-26.

The elevated nitrate, ^{99}Tc, and chromium observed in the groundwater at well 299-E33-16 appear to be local. Monitoring for this region of the groundwater began only when assessment-level monitoring began. Consequently, how long the nitrate and ^{99}Tc have been above the DWS is not known. If the local aquifer is hydraulically isolated from the BY crib plume, determining trends or changes in the groundwater chemistry at well 299-E33-16 may be difficult.

The origins of the contamination chemistry at well 299-E33-44 are not yet completely understood. Because of the lower nitrate-to-^{99}Tc ratio coupled with the very high uranium values, the contamination tends to look like tank-waste. A plausible source is the metal waste-contaminated zone just east of tank BX-102.

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4.0 DATA INTEGRATION AND CONTAMINANT MIGRATION CONCEPTUALIZATION

This section provides qualitative hypotheses and conclusions about the nature and distribution of contamination present in the B-BX-BY WMA. The bases for these observations are the data described in Chapter 3 and the appendices of this document.

4.1 CRITICAL OBSERVATIONS

When the spectral gamma logging database is considered collectively, several patterns of vadose zone contamination in the B-BX-BY WMA appear. These include the following:

- Cesium-137, the most widely distributed radionuclide identified by spectral gamma analysis, is measured in almost every drywell. Given the high solubility of ^{137}Cs in tank fluids and fluids derived from the treatment of tank fluids, ^{137}Cs provides a convenient marker of discharges from tank waste sources into the soil column.

- In many drywells (e.g., 22-01-01, 22-01-03, and 22-01-07), a maximum ^{137}Cs concentration (about 10 to 100 pCi/g) occurs within 1.5 m (5 ft) of the surface and diminishes in concentration with depth to about 1 pCi/g at 6 m (20 ft) below the surface.

- In several drywells, ^{137}Cs exists in concentrations that exceed the maximum spectral gamma detection level in sharply defined (high-density) zones. These zones frequently are about 1.5 m (5 ft) thick and located near the surface or near the tank bottom depth, 12 m to 15 m (40 to 50 ft) below the surface. High contamination surface zones are found in drywells 21-02-04, 21-08-07, 21-12-03, 22-08-01, 22-08-02, and 20-02-11. High contamination zones near the tank bottom occur in drywells 21-11-03, 21-10-05, 21-11-04, and 20-06-06. Two other zones occur at the 6 m to 8 m (20- to 25-ft) level (drywells 22-03-05 and 21-03-12), the level at which inlet pipes and transfer lines between tanks are located.

- Cobalt-60 is found in numerous boreholes with ^{137}Cs and tends to be present in the bottom part of the drywell (from about 15 m [50 ft] to 30 m to 40 m [100 to 130 ft]). Cobalt-60 concentrations generally are no greater than 1pCi/g and, in rare instances (drywells 22-04-09, 22-06-05, 22-08-02), peak at about 10 pCi/g. In several instances (e.g., drywells 22-08-02, 22-08-06, and 22-09-07), ^{60}Co is separated from ^{137}Cs, which remains near the top of the soil column. In other cases, both ^{137}Cs and ^{60}Co are found to the bottom of the drywell. At the lower depths, ^{137}Cs concentrations are less than 1 pCi/g, very close to lower detection limits.

- A large area of uranium contamination is present in the vadose zone east of tank 241-BX-102 at depths from 23 m to 40 m (75 to 130 ft) over about 697 m^2 (7,500 ft^2). As described in Section 3.2.2, this contamination is attributed to a metal waste discharge into the vadose zone from a 241-BX-102 tank outlet in 1951.

- In the B tank farm near 241-B-110, an extensive zone of contamination occurs in drywell 20-10-12. In addition to ^{137}Cs, ^{90}Sr is inferred to be present in fairly large

quantities. Contamination concentrations exceeded maximum detection levels at depths from 8 m to 30 m (25 to 100 ft). At depths between 30 m and 34 m (100 and 110 ft), ^{235}U is reported at levels between 100 and 1,000 pCi/g. However, this observation is suspect because ^{238}U, which should coexist with ^{235}U, is not reported in this drywell.

- Since the beginning of B-BX-BY tank farms operations, discharge of water into the local vadose zone has been sporadic and has varied in intensity. The sources of water include contaminated water from unplanned releases, natural precipitation, and, potentially, leaking water lines. The influences of these events on contaminant migration from the B-BX-BY WMA into the unconfined aquifer are difficult to gauge because of limited waste-site-specific groundwater monitoring activities. The largest known intentional releases occurred in the cribs, trenches, and reverse wells outside the B-BX-BY WMA and should have had little effect on contaminant migration within the vadose zone underlying the B-BX-BY WMA.

- Within the B-BX-BY WMA, natural precipitation events of varying intensity have occurred. The combination of highly permeable tank farm covers and vadose zone soils maximizes recharge rates from these events. However, correlation of specific recharge events from high-intensity precipitation events with contaminant migration is highly uncertain.

- The likelihood of water and waste transfer line leaks is high and a good percentage of these leaks probably are undetectable. Documentation of such leaks is limited.

- Evidence of plausible unconfined aquifer contamination from B-BX-BY WMA leaks is limited to one occurrence, ^{99}Tc and uranium spiking in drywell 299-E33-41 in 1997. Contamination is present in other wells, but the sources of the contamination are ambiguous. Given the general lack of B-BX-BY WMA monitoring before 1991 and the presence of vadose zone contamination for approximately three decades, the occurrence of similar previous events is plausible, but undocumented.

These observations clearly show that multiple contamination events have occurred, various sources provided the contamination, and varying degrees of contamination in the vadose zone have resulted.

4.2 CONCEPTUALIZATION OF PRIMARY VADOSE CONTAMINATION EVENTS

4.2.1 Surface Contamination Events

Spectral gamma logging data from the majority of drywells in the B-BX-BY WMA show ^{137}Cs concentrations between 10 and 100 pCi/g near the surface, followed by a rapid reduction in ^{137}Cs concentration to about 1 pCi/g within 6 m (20 ft) of the surface. This pattern suggests that the contamination caused by near-surface leaks is ubiquitous in the B-BX-BY WMA. Given the layers of piping that have been constructed near the surface to support the numerous operations in these tank farms and the relatively few leak incidents reported, many small leaks

probably have occurred over time as tank fluids were transferred. In a few drywells, narrow well-defined bands of higher ^{137}Cs concentrations exist near the surface, suggesting variability in the sources of contamination. In these cases, the rapid drop off to nominal concentration values still occurs.

Following the initial discharge of contaminants caused by these leaks, further migration of more mobile constituents apparently has occurred, presumably driven by relatively high local recharge. Local recharge sources could be natural precipitation or additional water pipe leaks. The spectral gamma logging data show this farther migration in the frequent observance of ^{60}Co currently located over a depth interval farther down in the soil column than ^{137}Cs. One of the best examples of this is found in drywell 22-08-02 where an above-detection-level concentration band of ^{137}Cs occurs at the 1 m to 2 m (3- to 8-ft) interval, a 1 to 10 pCi/g ^{137}Cs concentration occurs from 2 m to 15 m (8 to 50 ft), and a 0.1 to 10 pCi/g concentration of ^{60}Co occurs between 15 and 30 m (50 and 100 ft). In this drywell, ^{60}Co movement also was tracked in the gross gamma logging database (see Section 3.1.3) over 10 years. This crude chromatographic separation is expected because ^{60}Co normally is more mobile than ^{137}Cs in these fluids from leaking waste tanks.

Cobalt-60 and other mobile constituents easily could have migrated farther than 30 m (100 ft) down the soil column. Additional migration has not been observed because the drywells do not extend much farther and unconfined aquifer groundwater data are not available.

4.2.2 Tank BX-102 Contamination

Spectral gamma logging data for the B-BX-BY WMA show the most extensive region of contaminated vadose zone soil adjacent to and east of tank 241-BX-102. The primary contaminants are ^{238}U, ^{235}U, and ^{137}Cs. Smaller amounts of ^{60}Co and ^{125}Sb also are present. In the drywell closest to the southeast tank wall, drywell 21-02-04, a large high-concentration ^{137}Cs zone begins at 8 m (25 ft) below the surface and extends to the bottom of the drywell (about 70 m [230 ft]). Section 3.2.2 presented evidence that the uranium contamination could only have come from a metal waste source. The only known metal waste loss occurring near tank 241-BX-102 occurred in 1951 (see Appendix A).

A plausible scenario that explains the observed vadose zone contamination characteristics begins with a waste transfer event where metal waste was moved from tank BX-101 through tank BX-102 toward tank BY-103. During the transfer, the pipe between tanks BX-102 and BX-103 plugged and tank BX-102 began to fill. The liquid level rose above a sealed inlet port on the southeast part of the BX-102 tank wall, broke the seal, and discharged contaminated fluid into the soil column until the liquid level fell below the inlet port. A large amount of fluid discharged rapidly, creating and propagating a temporary saturated zone. The discharged liquid moved vertically down the side of the tank until it reached a local horizontally oriented high-permeability lens at a 23 m to 30 m (75- to 100-ft) depth. The fluid migrated laterally and eastward until insufficient liquid was available to maintain soil saturation. During this event, uranium and other soluble species were carried with the fluid. The data suggest that most of the ^{137}Cs dropped out of solution near the tank wall, but a small fraction of ^{137}Cs was sufficiently soluble to colocate with uranium.

Once the metal waste fluid stopped leaking from the tank inlet port and spreading rapidly through the soil, drainage began. The contaminated zone desaturated and largely vertical movement of contaminated fluid began. At this time, most of the uranium precipitated and the ^{137}Cs sorbed in place. Those contaminants remaining in solution, primarily uranium and ^{99}Tc, migrated with the draining fluid. Over time, additional recharge from natural precipitation or pipe leaks pushed contaminants deeper into the soil column and into the unconfined aquifer. The spikes of ^{99}Tc, uranium, and tank chemicals reported in borehole 299-E33-41 by Narbutovskih (1998) are likely an example of contaminants that have reached the unconfined aquifer from this contaminated zone.

4.2.3 Tanks BX-108, BX-110, and BX-111 Contamination

Tanks BX-108, BX-110, and BX-111 are identified as leakers and spectral gamma logs from several drywells support this conclusion. Several drywells between tanks BX-111 and BX-108 show elevated ^{137}Cs concentration between 11 m and 14 m (35 and 45 ft) below the surface. In each case, the zones of higher contamination are about 1.5 m (5 ft) thick. Cesium-137 concentrations exceeding the spectral gamma logging tool saturation levels occur in drywells 21-11-03 and 21-11-04. In drywell 21-08-07, a maximum ^{137}Cs concentration of about 80 pCi/g occurs at 11 m (35 ft) below the surface; the concentration reduces to about 1 pCi/g at 12 m (40 ft) below the surface. The depth of contamination suggests leakage near the bottoms of tanks BX-108 and BX-111. The limited extent of ^{137}Cs contamination in these drywells and the small liquid loss estimates for tank BX-108 (9464 L [2,500 gal]) both indicate that small quantities of contamination are present in the soil column at this location.

Around tank BX-110, drywells 21-10-03 and 21-10-05 indicate tank waste leaks. In drywell 21-10-03, ^{137}Cs concentrations above logging tool saturation occur from 3 m to 12 m (10 to 40 ft), 14 m to 15 m (45 to 50 ft), and 24 m to 25 m (80 to 82 ft) below the surface. This location suggests leakage from an inlet port. A second graph of drywell 21-10-03 differs from the first in that the two lower ^{137}Cs saturation zones are not shown. The discrepancy between the two graphs has not been reconciled. Despite this ambiguity, the relatively larger zones of high ^{137}Cs contamination in this drywell suggest the leak from tank BX-110 may be greater than the leak from either tank BX-108 or tank BX-111.

Just south of tank BX-111, in drywell 21-10-05, ^{137}Cs concentrations above spectral gamma logging tool saturation occur from 12 m to 15 m (40 to 48 ft) below the surface. This contaminated zone could be part of the proposed inlet port leak or a separate leak near the tank bottom.

Alternatively, significant contamination is shown in drywell 21-07-06, just east of drywell 21-10-05. In drywell 21-07-06, three zones of ^{137}Cs contamination above saturation occur. These zones are located at from 8 m to 9 m (25 to 30 ft), 12 m to 15 m (40 to 50 ft) and 18 m to 23 m (60 to 75 ft). Cesium-137 concentrations greater than 1,000 pCi/L are shown from 23 m to 30 m (75 ft to 100 ft) from the drywell bottom. These data suggest an additional source of leakage, such as a waste transfer line, from or near tank BX-107. Contaminants observed in drywells 21-10-05 and 21-07-06 may be connected.

Finally, a zone of ^{235}U contamination of approximately 100 pCi/L is shown at a depth of from 15 m 18 m (50 to 60 ft) in drywell 21-10-05. This occurrence is puzzling for several reasons. Uranium-238 should be present also, and is not identified. No historical record suggests the presence of metal waste in tank BX-110 or nearby waste transfer lines known to have carried metal waste and no other nearby drywell gamma logging data show uranium contamination. Further evaluation of the database is warranted.

4.2.4 B-110 Contamination

Spectral gamma logging data from drywells surrounding tank B-110 are unique in the B-BX-BY WMA data set because they indicate that ^{90}Sr is one the contaminants present in vadose zone soil. A large contamination zone from 8 m to 30 m (25 to 100 ft) is shown for drywell 20-10-12. The region from 18 m to 30 m (60 to 100 ft) is inferred to contain large but unspecified concentrations of ^{90}Sr. Substantial ^{137}Cs concentrations also are present, exceeding the saturation level from 8 m to 30 m (25 to 100 ft), then decreasing from about 5000 pCi/L to 10 pCi/L. Strontium-90 also is indicated in drywell 20-10-02 at 23 m to 24 m (75 to 80 ft) below the surface just southeast of drywell 21-10-12. The location of the top of the contamination zone at 8 m (25 ft) suggests that $^{137}Cs/^{90}Sr$ recovery waste leaked from an inlet port on the northern wall of tank B-110 and moved vertically down the tank wall with limited lateral movement to the southeast. Waste transfer records show that excess liquids were present in tank B-110 in 1968 and 1969, a condition that permits leakage from an inlet port.

A small zone of ^{235}U contamination is shown at from 30 m to 32 m (100 to 105 ft) in drywell 20-10-12. As discussed in Section 4.2.3, a rational explanation for this occurrence is not readily obvious and further evaluation of the data is warranted.

4.2.5 Contamination from Other Tanks

The available spectral gamma data and the official list of assumed tank leaks indicate small amounts of leakage from several other tanks, including tanks BY-103, B-105, and B-107. In each case, a small number of drywells surrounding the tanks show distinct bands of contaminant concentration that exceed gamma logging saturation limits. The contaminant is presumably ^{137}Cs because ^{137}Cs was measured directly above and below these zones. At tank BY-103, drywell 22-03-05 shows an above-saturation band between 25 and 45 ft and elevated ^{137}Cs concentrations at between 14 m to 30 m (45 and 100 ft) deep, peaking around 1,000 pCi/L at the top and diminishing with depth to about 100 pCi/g. Just west of this drywell, in drywell 22-03-06, a 100 pCi/g ^{137}Cs spike is shown at 13 m (42 ft) below the surface. This location of maximum concentration suggests leakage from an inlet port near drywell 22-03-05 and spreading west to drywell 22-03-06.

In drywell 20-05-06, a thin band of ^{137}Cs contamination at concentrations exceeding spectral gamma logging saturation limits occurs between about 15 m (48 and 50 ft) depth. In drywell 20-06-06, a similar small zone occurs between 15 m and 16 m (50 and 55 ft). These contamination zones suggest one or more leaks from the bottom of tank B-105. Drywell 20-07-02 near tank B-107 shows a high ^{137}Cs concentration zone (maximum of about 1,000 pCi/g) between 12 m and 18 m (40 and 60 ft) depth. These contamination zones suggest one or more leaks from the bottom of tank B-107.

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5.0 RECOMMENDATIONS FOR FURTHER CHARACTERIZATION OF THE B-BX-BY WMA

Chapters 1 through 3 present information pertinent to the occurrence of contaminants in the vadose zone underlying the B-BX-BY WMA and the groundwater contamination observed in samples analyzed from groundwater monitoring well 299-E33-41. Chapter 4 provides qualitative hypotheses of events leading to the observed vadose zone and aquifer contamination.

From these observations and process knowledge, we conclude that the primary locations of interest for additional aquifer contamination have been identified. For most of these areas, contamination extensive enough to warrant remediation is not expected. However, further characterization is recommended primarily because of the following four types of data gaps.

- The volumes of most leaks are not well documented because no clear means of measuring leaks was available.
- Measurements of leaked waste fluids are rare and incomplete.
- Groundwater monitoring data in the unconfined aquifer underlying or directly downstream of the B-BX-BY WMA is essentially nonexistent for the period before 1991. Consequently, any number of mobile contaminant releases from the vadose zone into the unconfined aquifer could have occurred between 1951 and 1991 and gone undetected.
- The spectral gamma data do not provide information about the nature and extent of non-gamma-producing contaminants. In particular, the distribution and inventory of ^{99}Tc is of interest.

5.1 DESCRIPTION OF CHARACTERIZATION ALTERNATIVES

The primary goal of additional characterization is to determine the nature and extent of tank waste contaminants in the vicinity of known or suspected leaks. This is to be done primarily through sampling soils in the regions of interest and analyzing the samples for expected contaminants of concern; soil water pH, electrical conductivity, moisture content, and, if feasible, hydrologic properties. Of particular interest are known mobile constituents, ^{99}Tc, uranium, and nitrate. Other contaminants, particularly ^{137}Cs and ^{60}Co, are of interest because they provide some indication of contaminant migration and distribution. Neither radionuclide is expected to contaminate groundwater to unacceptable levels in the future. Finally, spectral gamma and neutron probe logging for moisture is recommended where feasible. The following sections identify the proposed locations and methods of collecting samples.

5.1.1 Tank BX-102 Area Characterization

The large uranium contamination area occurs at the 23 m to 40 m (75- to 130-ft) depth over a large oval area just south and east of tank BX-102. The 1997 ^{99}Tc and uranium peaks in drywell 299-E33-41 are assumed to have been derived from this contamination area. Thus, the

region of potential contamination includes the entire vadose zone below 23 m (75 ft). The primary question to be answered is the current distribution and total inventory of ^{99}Tc in this region. Estimates of ^{99}Tc concentrations in metal waste (Agnew 1997) and the leak volume suggest that about 4 Ci of ^{99}Tc initially were disposed of. Conceivably, much of the ^{99}Tc has already reached the unconfined aquifer.

To characterize this area, one recommendation is to drill a borehole to the water table in the vicinity of the highest observed uranium contamination. Another option is to extend an existing drywell in the same area. Periodic sampling with depth beginning at about 23 m (75 ft) down to groundwater is recommended. Depending on the findings and technical feasibility, several shallow surface samplings down to the 23 m to 30 m (75- to 100-ft) depth to further define contaminant distribution may be warranted. Shallow sampling techniques, such as using a cone penetrometer, may be impeded by the quantity of piping in the area and the high gravel content of the soils.

5.1.2 BX-110, BX-107 Area Characterization

Drywells 21-07-06, 21-10-03, and 21-07-06 show multiple sections of high ^{137}Cs content between 3 m and 30 m (10 and 100 ft). Cobalt-60 also is present and uranium may be present. The primary uncertainty to be addressed here is the nature and extent of contaminants, particularly mobile constituents, in this area. To clear up this uncertainty, surface samplings (e.g., cone penetrometer) from 3 m to 30 m (10 to 100 ft) in this area are recommended. If mobile constituents are not found, further characterization is not required. If mobile constituents are found, an evaluation of potential impact on groundwater should be made before deciding on additional characterization.

5.1.3 B-110 Area Characterization

Drywell 20-10-12 shows a large band of contamination from 8 m to 30 m (25 to 100 ft) that includes ^{137}Cs and ^{60}Co, probably ^{90}Sr, and possibly uranium. Drywell 21-10-02 also shows a region of probable ^{90}Sr contamination. The primary uncertainty to be addressed here is the nature and extent of contaminants in this area. In particular, ^{90}Sr mobility may be enhanced by complexation with organic species. To clear up this uncertainty, surface samplings (e.g., cone penetrometer) from 3 m to 30 m (10 to 100 ft) in this area are recommended. In addition to the normal suite of chemical analyses, some effort should be made to measure the appropriate organic species to address the potential impact of these species on contaminant migration. If mobile constituents are not found, further characterization is not required. If mobile constituents are found, an evaluation of potential impact on groundwater should be made before deciding on additional characterization.

5.1.4 BY-103 Area Characterization

Drywell 22-03-05 shows a band of above-saturation ^{137}Cs concentration from 8 m to 14 m (25 to 45 ft) in relatively large concentrations (100 to 1,000 pCi/L) down to 29 m (95 ft). A smaller less extensive and less contaminated zone is shown nearby in drywell 22-03-06. The primary uncertainty to be addressed here is the nature and extent of contaminants in this area.

To clear up this uncertainty, surface samplings (e.g., cone penetrometer) from 3 m to 30 m (10 to 100 ft) close to drywell 22-03-05 are recommended. If mobile constituents are not found, further characterization is not required. If mobile constituents are found, an evaluation of potential impact on groundwater should be made before deciding on additional characterization.

Evaluation of the historical gamma data has shown significant vertical movement of ^{60}Co in the vadose zone to the west and southwest of tank BY-103. Some evaluation of characterization efforts to further define mobile constituent migration should be completed in the DQO process.

5.1.5 241-B Diversion Box Area Characterization

Metal waste leaks from diversion box 241-B characterization were reported in 1951. No gamma logging data or any other kind of characterization data are available for this area. Because the metal waste is the most contaminated waste stream leaked in the B-BX-BY WMA, shallow characterization is recommended. The primary uncertainty to be addressed here is the nature and extent of contaminants in this area. Uranium and, possibly, ^{99}Tc should be present. To clear up this uncertainty, surface samplings (e.g., cone penetrometer) from 3 m to 15 m (10 to 50 ft) are recommended. If mobile constituents are not found, further characterization is not required. If mobile constituents are found, an evaluation of potential impact on groundwater should be made before deciding on additional characterization.

5.1.6 Characterization of Other Contaminated Areas

Other contaminated areas have been identified in this report. These include the BX-111 area, the BX-108 area, the B-107 area, the B-105 area, and the ubiquitous presence of surface contamination in the B-BX-BY WMA. These areas currently are not recommended for further characterization because the levels of contamination are either minimal (100 pCi/L of ^{137}Cs or less) or concentrated in very small areas (e.g., a 1.5 m [5-ft]-thick zone in an isolated drywell). If characterization of the more contaminated areas in the B-BX-BY WMA reveal larger inventories of contaminants of concern, further characterization of these areas should be reevaluated.

5.2 RANKING OF POTENTIAL CHARACTERIZATION AREAS

Of the several target areas described in Section 5.1, we recommend that top priority be given to evaluating the metal waste spill east of tank BX-102 because it is the largest known area of contamination and the waste fluid is the most highly contaminated of all waste released into the vadose zone underlying the B-BX-BY WMA. The next most important contamination zone is the area around tank B-110 where ^{90}Sr is suspected to be present in the vadose zone with its mobility enhanced by complexation with organic species. The remainder of the contamination zones are recommended as third priority targets.

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APPENDIX A

HISTORICAL BACKGROUND OF B, BX, AND BY TANK FARMS OPERATIONS AND CONTAMINATION EVENTS

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APPENDIX A

HISTORICAL BACKGROUND OF B, BX, BY AND TANK FARMS OPERATIONS AND CONTAMINATION EVENTS

This appendix includes narrative description from *Historical Vadose Zone Contamination from B, BX, and BY Tank Farm Operations*, HNF-5231, Rev. 0 (Williams 1999). This appendix includes only the narrative of the B, BX, and BY tank farm operations that relate to contaminant discharges into the vadose zone underlying the B-BX-BY Waste Management Area and the surrounding cribs, trenches, and wells. The appendix also includes enlarged figures of the piping systems placed in the B-BX-BY Waste Management Area for the various projects. This appendix also includes the *Hanford Works Monthly Report for February 1951*, which describes the metal waste leak from Tank BX-102.

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HISTORICAL VADOSE ZONE CONTAMINATION FROM B, BX, AND BY TANK FARM OPERATIONS

SEPTEMBER 1999

Prepared by

J.C. Williams
Fluor Daniel Northwest
Richland, Washington

Prepared for

Lockheed Martin Hanford Corporation
Richland, Washington

TABLE OF CONTENTS

ABBRVIATIONS/ACRONYMS

AEC	Atomic Energy Commission
DCRT	Double-contained receiver tank
ITS	In-tank solidification
MW	Metal waste
PUREX	Plutonium and uranium extraction
REDOX	Reduction and oxidation
TBP	Tributyl phosphate
UPR	Unplanned release
UR	Uranium recovery
WIDS	Waste Information Data System

HISTORICAL VADOSE ZONE CONTAMINATION FROM B, BX, AND BY TANK FARM OPERATIONS

1.0 INTRODUCTION

This document is a collection of historical information regarding radioactive contamination of the soil surface and vadose zone in the vicinity of the 241-B, 241-BX, and 241-BY tank farms. Specifically, the historical information is compiled for the tank farms, all known liquid radioactive waste disposal sites (cribs), and all known unplanned releases (UPRs) in an approximately 500 meter square area. The area extends from 12th Street south to the 207-B retention basin and from the 216-BX trenches to the east boundary to B Farm (see Figure 1 in Appendix 7). Releases are included from initial construction in 1944 to the present. A list of disposal sites is contained in Appendix 1. A list of UPRs is included in Appendix 2.

Nonradioactive releases such as fuel spills and septic tanks, and buried radioactive solid waste are excluded from this report. Water discharges to the soil, either from precipitation, water line leaks, or decontamination activities are addressed in Gaddis (1999).

The timeline of events is included in Appendix 3. A glossary is provided in Appendix 4.

The primary focus of this report is on cribs rather than spills. Crib disposal outlets are typically located 3 to 10 meters (9 to 30 ft) below grade, while most spills occur above ground level and contaminate only the surface. Many spill sites were quickly cleaned up and decontaminated. Additionally, the sitewide volume of waste discharged to cribs is more than 100 times the volume of waste leaked from tanks (Consort 1994).

The 216-B-7 cribs, the 216-B-8 crib, and the 216-B-11 reverse wells are located within 241-B tank farm, in Operable Unit 200-BP-7. In addition to the tank farms, this study includes the 216-BY cribs, the 216-B-57 trench and the 216-B-61 crib (never used) in Operable Unit 200-BP-1; the 216-BX trenches in Operable Unit 200-BP-3; and the 216-B-51 French drain in Operable Unit 200-BP-4.

The groundwater beneath the B/BX/BY tank farm complex is 123 m (400 ft) underground and relatively flat. The flatness makes it difficult to ascertain the flow direction. Generally, groundwater in the 200-East Area moves in a northwesterly direction, but there is a southeasterly flow between Gable Mountain and Gable Butte. The location of the division between the flows is not known with certainty, and may be near the B/BX/BY tank farms. The groundwater level beneath 200-East Area has been decreasing gradually since B pond was decommissioned in 1995 (Hartman 1999).

2.0 SUMMARY AND CONCLUSIONS

A number of significant discharges of radioactive contamination to the surface soil and vadose zone occurred throughout the operating history of the Hanford Site. The most significant discharges to the area of interest around the 241-B, -BX, and -BY farm complex are summarized as follows:

- In-tank solidification (ITS) condensate discharged to 216-B-50 and 216-B-57 represents one of the largest volumes of liquid waste, 143 million liters (38 million gal), discharged to the soil at the Hanford Site.
- The B Farm cribs (216-B-7A and B, 216-B-8, and 216-B11A and B) received 100 million liters (26 million gal) of a combination of waste streams 5-6 and 2C, and evaporator condensate.
- With the exception of 216-B-50, the BY cribs received 31.7 million liters (8 million gal) of scavenged tributyl phosphate (TBP) waste (low-level, non-transuranic liquid waste).
- The BX trenches received 14.8 million liters (4 million gal) of waste stream 1C waste.
- The largest spills occurred at 241-BX-102, UPR-200-E-5 (346 700 liters [91,000 gal]) and UPR-200-E-131 (265 000 liters [70,000 gal]).

Other cribs in 200 East Area are outside the scope of this report but are mentioned here for comparison. The 216-B-12 crib received 580 million liters (153 million gal) of TBP plant concentrator condensate. The BC cribs and trenches received 110 million liters (29 million gal) of scavenged TBP waste. The 216-B-9 crib received 36 million liters (10 million gal) of 5-6 waste. The 216-B-5 reverse well received 31 million liters (8 million gal) of 224 waste. The 216-B-10A and 216-B-10B cribs received 10 million liters (3 million gal) of floor drainage from the 292-B Building and some waste from the 222-B decontamination sink and sample slurper.

This report supports previous work on discharges to cribs, ditches, and ponds associated with B Plant (Williams, 1995). Other studies similar to these could be made for the other separation plants and tank farms. Upon completion, these studies can be integrated into a single report. This approach is necessary to account for waste streams that affect more than one plant or tank farm complex. For example, the uranium recovery mission affected U Plant, U farm, B, BX, and BY farms, C farm, and T, TX, and TY farms.

3.0 FACILITIES HISTORICAL BACKGROUND

The 241-B tank farm contains 12 first-generation, reinforced-concrete tanks with mild steel liners covering the sides and bottoms. The tanks are 23 m (75 ft) in diameter and 4.9 m (16 ft) deep, with a capacity of 2 million liters (530,000 gal). The tanks are arranged in four rows of three. The tanks in a row are piped together so that when the first tank fills, it will overflow into the second tank, and the second into the third. Three diversion boxes are provided in B farm.

The farm also contains four smaller tanks that are 6.1 m (20 ft) in diameter and hold 208 000 liters (55,000 gal). These four tanks are piped to diversion box 241-B-252 and to cribs 216-B-7A and 216-B-7B.

The 241-BX tank farm contains 12 tanks of an identical design to 241-B, also arranged in four 3-tank cascades. BX farm has no 208 000-liter tank (55,000 gal) and only one diversion box, 241-BX-153.

The 241-BY tank farm contains 12 second-generation tanks similar to the B and BX farm tanks, but with a 2.9 million liter (758,000 gal) capacity. The BY tanks are arranged in four 3-tank cascades, each of which is piped to the outlet of a BX farm cascade. BY tank farm contains no 208 000 liter (55,000 gal) tanks and no diversion boxes (DiLorenzo 1994).

Other facilities are contained within the B/BX/BY tank farm complex. Liquid waste disposal sites in B farm include the 216-B-8 crib, the BX trenches, and the BY cribs. The 242-B evaporator facility includes the Evaporator Building, the 216-B-11A and 216-B-11B reverse wells in B farm, and the 242-B-151 diversion box. BX farm contains the 244 BXR vault and seven diversion boxes that were used for the uranium recovery mission from 1952 to 1957. The 244-BX double-contained receiver tank (DCRT) is also in the BX farm. Some abandoned ITS equipment is located in the BY tank farm. Piping for saltwell pumping is located throughout the B/BX/BY complex.

The B/BX/BY tank farm complex operations can be separated into five distinct historical eras:

- From 1943 to 1945, B tank farm received liquid waste from the Manhattan Project bismuth phosphate plutonium separation operations.
- From 1946 until B Plant shutdown in 1952, the tank farms were expanded and received liquid waste from the bismuth phosphate operations. Liquid waste disposal to the soil column was initiated.
- From 1952 to 1958, high-level waste was sent to U Plant for uranium recovery and scavenging. Scavenged waste was discharged to cribs. Low-level process condensate was also discharged to cribs.
- ITS operations occurred from 1965 to 1974. Condensate was discharged to cribs.
- Tank farm interim stabilization (saltwell pumping) and isolation began in 1975.

Sanitary water was not supplied to the B/BX/BY tank farms during wartime bismuth phosphate operations, but was supplied to the 241-B evaporator after the war. During uranium recovery operations, sanitary water was supplied to the 271-BXR control house. Later, during ITS operations, sanitary water was supplied to the 2707-BY change house, 241-BY-302 compressor building, and the 241-BY-154 operating building. Currently, all sanitary water piping is capped off and abandoned.

3.1 Wartime Bismuth Phosphate Operations

The 241-B tank farm was constructed in 1943-1944 as part of the Manhattan Project to provide storage for the radioactive liquid waste produced at B Plant. Figure 2 shows the facilities constructed at this time. B Plant used the bismuth phosphate process to separate plutonium from irradiated fuel slugs.

The bismuth phosphate process produced five waste streams:

- MW, also called metal waste, was the byproduct from the plutonium separation phase of the bismuth phosphate process. Metal waste contained unfissioned uranium and approximately 90% of the fission products of the irradiated fuel.

- 1C, also called first-cycle waste, was the byproduct from the first plutonium decontamination cycle of the bismuth phosphate process. This waste contained about 10% of the fission products of the irradiated fuel.

- 2C, also called second-cycle waste, was the byproduct from the second and last plutonium decontamination cycle of the bismuth phosphate process. This waste contained less than 0.1% of the fission products of the irradiated fuel.

- 224 waste was low-level liquid waste from the 224-B plutonium concentrator facility. This waste stream was the primary contributor to plutonium contamination of the soil. This waste was routed to the 216-B-361 settling tank, and then discharged to the 216-B-5 reverse well near B Plant. These two facilities are outside the scope of this study, but are described in Smith (1980).

- 5-6 waste was low-level liquid waste from individual process cells in B Plant. Drainage from the cells was stored in the 5-6 tank before being discharged to the 216-B-361 tank and the 216-B-5 reverse well.

MW, 1C, and 2C were stored in the B farm tanks. These waste streams were also sent to the 241-C tank farm, which is outside the scope of this study (Parker 1944).

Ground disposal of aqueous industrial waste, relying on the ion-exchange properties of the soil to decontaminate the water as it percolates to the aquifer, was a commonly accepted method in the 1940s. The ability of Hanford topsoil and substrate to adsorb radioactive material was tested at the Clinton site in Tennessee (now Oak Ridge National Laboratory) and at the University of California at Berkeley in 1944. Tests determined that ground disposal of 5-6 and 224 was acceptable, but ground disposal of 1C and 2C was not. Methods to treat 1C and 2C to facilitate ground disposal were investigated at the time, but were unsuccessful (Parker 1944; Patterson 1945; Leader 1945).

3.2 Postwar Bismuth Phosphate Operations

In September 1946, the Army Corps of Engineers Manhattan District selected General Electric Company to replace DuPont as site prime contractor. Pursuant to the McMahon Atomic Energy Act of 1946, control of the Hanford Site passed from the Army to the civilian Atomic Energy Commission (AEC) on January 1, 1947. The AEC opted to maintain Hanford as a permanent facility rather than dismantle it, as happened to many other wartime munitions plants. Wartime production had filled all available waste tank space, so plans were made to increase high-level waste storage capacity and to recover some tank space. These plans included disposing of the relatively low-level 2C waste into the ground and concentrating the intermediate-level 1C waste in an evaporator. Plans were also made to recover the unfissioned uranium in the MW (by 1947, most of the world's known supply of uranium was in Hanford waste tanks). From 1947 to 1949, many new facilities were constructed at Hanford. The BX and BY tank farms, facilities for the planned uranium recovery mission (see section 3.3), and other facilities beyond the scope of this report (TX tank farm, Z Plant, H Reactor, DR Reactor, Hot Semi-Works) were all built during this period (Gerber 1991). Figure 3 shows facilities constructed for postwar bismuth phosphate and waste disposal operations.

Disposal of 224 waste in a reverse well was quickly recognized as a "definite mistake" and the waste was rerouted to tank 241-B-201 in 1946. The waste settled in the tank and the supernate overflowed to the 216-B-7A and 216-B-7B cribs. 224 had an average Pu concentration of 99 μg/L and an average β-emitter concentration of 26 μCi/L. Because of the potential for groundwater contamination, the 216-B-5 reverse well was decommissioned in October 1947. The 5-6 waste was temporarily combined with 224 waste and rerouted to the 216-B-7A and 216-B-7B cribs until August 1948, when the 216-B-9 crib near B Plant was built for 5-6 waste disposal. Crib 216-B-9 is outside the scope of this report. Settling tank 241-B-201 was removed from service in October 1948 when it filled with sludge. The influent line was rerouted to 241-B-204, and tanks 241-B-202, -203, and -204 were tied together in a cascade series. The crib line was rerouted to 241-B-202, the last tank in the cascade (Brown 1948; Keene 1951; Williams 1995).

Ground disposal of waste was always regarded as a temporary expedient, and methods of treating 224, 5-6, and other waste types by such means as evaporation, scavenging, or ion exchange were investigated. Experiments with 2C revealed that most activity was concentrated in the sludge settling at the tank bottom, leaving a low-activity supernatant that met existing criteria for ground disposal. The continuing shortage of waste tank space led to the decision to crib 2C after cascading and settling (Piper 1949; Burns 1949; Brown 1950).

The 216-B-8 crib was constructed in 1948 in B farm to dispose of 2C waste. Initially, the crib was piped to a blind riser in B farm, accessible via an overground line, and waste was discharged one month per year. From September 1949 to December 1950, the average activity of 2C discharged to the crib was 1.5 μg/L of Pu and 26 μg/L of beta emitters. In May 1951, the crib line was piped to the 241-B-112 tank, the final tank in the cascade series used for 2C storage, and the cascade continuously overflowed to the crib. In July 1951, when 216-B-9 reached its radionuclide capacity, 5-6 waste was combined with 2C waste and sent to the 241-B-110/111/112 cascade and the B-8 crib. The crib was isolated in December 1951. Between 1948 and 1952, 27.2 million liters (7.2 million gal) of 2C waste was disposed of (H-2-1984; Piper 1949; Brown 1950; Keene 1951; Williams 1995).

The 242-B evaporator was built in 1951 to process 1C waste. Operations began December 14, 1951. The evaporator received 1C waste from feed tank 241-B-106 via the 242-B-151 diversion box. Evaporator condensate was sent to the 216-B-11A and 216-B-11B reverse wells. In the first half of 1952, this condensate had an average plutonium concentration of 0.152 μg/L and an average beta emitter concentration of 0.013 μCi/L. Cooling water was sent to B pond via the 207-B retention basin. Evaporator bottoms were sent to the 241-B-107, -108, and -109 cascade. This waste was then re-evaporated in a second pass. From 1952 to 1954, the 242-B evaporator reclaimed 26.5 million liters (7 million gal) of tank space in B, BX, and BY farms (General Electric 1952; Anderson 1990).

B Plant ceased operations in August 1952 and was shut down in October. When the 242-B evaporator was needed for scavenged TBP waste, ground disposal of 1C was pursued. In May 1953, direct disposal of 1C to specific retention trenches was approved, at a maximum discharge rate of 5280 L/m^2 (150 gal/ft^2) in order to ensure retention of liquid in the soil. Evaporation of 1C was discontinued in August 1953. Approximately 17 million liters (4.5 million gal) of 1C in 200-East and 200-West Areas had not been evaporated at that time. From February to November 1954, 7.5 million liters (2 million gal) of 1C were sent to the BX trenches. Trench disposal of evaporator bottoms was approved in June 1954, and 4.4 million liters (1.2 million gal) were discharged to 216-B-37 in August (Healy 1953; Anderson 1990; Carpenter 1953; Williams 1995). Details of 1C discharges to the BX trenches, including analytical data, are provided in Appendix 5.

Four UPRs are associated with bismuth phosphate operations, three in 1951 and one in 1952. DeFord (1995) describes soil contamination at 241-BX-103 believed to have occurred in 1951, but not assigned a UPR number. The best available information suggests that this contamination is in fact UPR-200-E-5. General Electric (1951) describes a tank leak between 241-BX-102 and 241-BX-103 resulting from a plugged cascade line that released 346 700 liters (91,600 gal) of MW containing 20 500 kg (22.5 tons) of depleted uranium. This is consistent with both DeFord (1995) and the WIDS database printout for UPR-200-E-5. The other 1951 UPRs are UPR-200-E-4 and UPR-200-E-73, both of which leaked an unknown amount of MW from diversion box 241-B-151. In December 1952, 1C leaked from an overground line at 241-BY-107 (UPR-200-E-105) (WIDS).

3.3 Uranium Recovery Operations

U Plant was originally constructed during World War II as a bismuth phosphate plant, but was not needed for that purpose so the facility was used as a simulator. It was modified in 1951 for uranium recovery operations using the TBP process. For this reason, U Plant was frequently referred to as the "TBP Plant." Beginning in 1952, MW was sluiced from B, BX, and BY farms, treated in the 244-BXR vault, and transferred via the 241-BXR-151 diversion box to U Plant. MW from C, T, and U farms was also sent to U Plant for uranium recovery. Until T Plant was shut down in 1956, newly generated MW was also sent to U Plant for uranium recovery (Rodenhizer 1987; Anderson 1990).

The uranium recovery facilities in the B/BX/BY tank farm complex include the 244-BXR vault, seven diversion boxes (one for B farm and three each for BX and BY farms) and associated transfer lines, modifications to the B farm underground piping system, and the BY cribs. Figure 4 shows facilities constructed for the uranium recovery mission.

Uranium recovery operations produced two waste streams. TBP waste, concentrate from the waste concentrator, was returned to the tank farms, including the B/BX/BY complex. The design called for the same volume of TBP waste to be produced as the volume of MW processed, but inefficiencies in the process resulted in approximately two liters of TBP waste produced for every liter of MW processed. A total of 215 million liters (56.7 million gal) of TBP waste was produced. Low-level waste included condensate from the feed concentrator, waste concentrator, and HNO_3 fractionator. This waste was discharged to various cribs that are outside the scope of this report. Cooling water and cell drainage were discharged to U pond, also outside the scope of this report (Waite 1991; DiLorenzo 1994; General Electric 1951b).

Despite additional tank farm construction and ongoing volume reduction efforts, waste tank space was not sufficient to support both the uranium recovery mission and plutonium production. To reduce the volume of stored waste, TBP waste was concentrated in the 242-T and 242-B evaporators beginning in September 1953. Additionally, a ferrocyanide scavenging process was developed to remove the principal long-lived fission products, ^{137}Cs and ^{90}Sr, from the TBP waste to enable disposal of the waste supernate to cribs. Beginning in September 1954, TBP waste was scavenged in U Plant to remove Sr and Cs. Beginning in November 1955, TBP waste that had been returned to the B/BX/BY farms and to C farm was retrieved and scavenged in the 244-CR vault. From scavenging (in U Plant or 244-CR), waste was sent to the BY tank farm for settling, then to the BY cribs from 1954 to 1957 (Waite 1991).

Average settling time was approximately a month. After settling, the supernate was sampled and, if within limits, discharged to the cribs. Crib size and spacing were based on anticipated discharge rates. Criteria for cribbing were a maximum of 3.17E07 L/m^2 (6,000 gal/ft^2), and a maximum concentration of ^{137}Cs and ^{90}Sr of 0.08 to 0.10 μCi/mL. This would result in a maximum of 2 000 curies of each isotope per 3.2-m^2 (30 ft^2) crib. Concentrations of 0.2 μCi/mL could be discharged if the volume were reduced proportionally, but could never be outside the range of 1.59E07-3.1E07 L/m^2 (3,000-6,000 gal/ft^2) because of scattering and percolation limitations. Discharge of concentrations greater than 0.2 μCi/mL required prior approval of the Radiological Sciences Department. Samples were taken from the discharge line for every 189 000 L (50,000 gal) discharged. (Clukey 1951)

Cribbing of scavenged TBP waste began in November 1954, the week after 1C cribbing was finished. Approximately 155 million liters (41 million gal) of scavenged TBP waste was discharged to the ground. Of this, approximately 44 million liters (12 million gal) resulted from in-farm scavenging in the 244-CR vault. A total of 34 million liters (9 million gal) was discharged to the BY cribs, with an additional 1.5 million liters (400,000 gal) discharged to 216-B-42, one of the BX trenches, in 1955 (Waite 1991; Williams 1995). Details of scavenged TBP waste discharges to the BY cribs, including analytical data, are provided in Appendix 6.

In May 1955, groundwater contamination was noted at the 216-B-8 crib, where the 2C waste had been discharged. In October 1955, groundwater contamination was noted at the 216-B-42 trench. Discharge of scavenged TBP waste to the BY cribs was discontinued in December 1955 when ^{137}Cs was detected in the groundwater (seven of the eight cribs were in use at that time). Waste was diverted to the BC cribs (outside the scope of this report). In February 1956, ^{60}Co was detected under the BY cribs at well E33-4 at 100 times the allowable limit (Kasza 1993; DeFord 1995).

Eight UPRs are associated with uranium recovery operations. In April 1953, MW leaked from an overground line at 241-B-102 (UPR-200-E-108). In June 1953, the underground cooling water drain line from 242-B to the 207-B retention basin leaked (UPR-200-E-79). In November1953, TBP leaked from a tank riser at 241-B-104 (UPR-200-E-109). Three diversion box leaks occurred in 1954 (UPR-200-E-6 and UPR-200-E-75 at 241-B-153, and UPR-200-E-74 at 241-B-152). In September 1955, scavenged TBP overflowed from flush tank 216-BY-201 (UPR-200-E-9).

There is a discrepancy regarding the type of waste involved in UPR-200-E-110. WIDS states that UPR-200-E-110 leaked 1C waste from a valve pit at 241-BY-112 in August 1955. However, Anderson (1990) states that 241-BY-112 never held 1C. MW was being sluiced from 241-BY-112 in August 1955, and this is most likely the correct waste type.

3.4 In-Tank Solidification Operations

Following the end of uranium recovery operations, many tanks in the B/BX/BY farms received PUREX coating waste from C farm. Concern over the integrity of single-shell tanks in the early 1960s (the first confirmed tank leak was in 1959) resulted in the decision to remove all liquid waste supernate from single-shell tanks. The ITS system was used to concentrate nonboiling waste to produce a partially mobile salt cake (Liverman 1975; Rodenhizer 1987; Anderson 1990).

Two ITS systems were installed in the BY tank farm. ITS#1 (heated air circulated through tank waste) was installed for tanks 241-BY-101 and 241-BY-102 and began operation in 1965. ITS#2 (in-tank heater) was installed for 241-BY-111 and 241-BY-112 and began operation in 1968. By 1971, ITS#2 extended to all remaining BY tanks, and ITS#1 was converted into a cooler for ITS#2. The ITS system was tied into BX farm in 1971 and B farm in 1973. Disappointing performance resulted in ITS being superseded by saltwell pumping and the system was shut down in 1974 (Anderson 1990). The ITS facilities are shown in Figure 5.

Beginning in 1968, all tanks constructed or planned have been a double-shell design. The AEC decided in 1968 to remove all liquid waste from single-shell tanks by 1975, using ITS. When this proved unfeasible, saltwell pumping replaced ITS as a method of liquid waste removal (Williams 1968; Liverman 1975).

The ITS system produced two waste streams. Concentrate from the ITS units was discharged to the B/BX/BY tank farms. The concentrate contained an average of 50% interstitial liquid, which

was later reclaimed by saltwell pumping. The 242-T and 242-S evaporators performed a similar ITS function in 200-West Area (Liverman 1975; Anderson 1990).

Condensate from ITS#1 was sent to the 216-B-50 crib from ITS#1 startup in 1965 to ITS #2 shutdown in 1974. The 216-B-60 trench was constructed in 1969 to replace this crib but was never used. Condensate from ITS#2 was sent to the 216-B-57 trench from ITS#2 startup in 1968 to shutdown in 1974 (Liverman 1975; Williams 1995).

ITS received some waste from waste fractionization operations that were conducted from 1968 to 1978 in B Plant. Waste fractionization removed heat-producing isotopes, principally ^{90}Sr and ^{137}Cs, from PUREX waste to allow safe evaporation of this waste to salt cake. B Plant was reconfigured to remove Cs and Sr from the waste, and the 244-AR vault was constructed to serve as a processing and transfer facility. Boiling waste from the PUREX plant, or PUREX waste stored in A and AX tank farms, was sent to B Plant via the 244-AR vault. REDOX waste supernate from SX farm was also sent to B Plant for waste fractionization. High-level waste from waste fractionization was sent to single-shell tanks in A and AX farms in the 1960s and early 1970s, and to double-shell tanks in AY farm in the late 1970s. Low-level liquid waste was concentrated in an evaporator in cell 23 of B Plant, with the bottoms routed to ITS and the condensate discharged to various cribs that are outside the scope of this study (Caudill 1964; Liverman 1975; Williams 1995).

Four UPRs are associated with ITS operations. Two diversion box leaks occurred in January 1968: UPR-200-E-38 at 241-B-152 and UPR-200-E-76 at 241-B-153. In January 1972, a pump being transported to the burial ground for disposal dripped contamination from the truck to the roadway (UPR-200-E-43). In November 1972, an unknown amount of contaminated flush water sprayed from a pump in 241-BY-112 (UPR-200-E-116) (WIDS).

3.5 Stabilization and Isolation

Eight leaking single-shell tanks were identified in B/BX/BY between 1968 and 1974. In 1971, a leak from 241-BX-102 (UPR-200-E-131) resulted in an underground plume that required relocation of nearby water lines. In accordance with Hanford operating policy at the time, liquid waste removal from tanks of questionable integrity was expedited and the tank was removed from service. Interstitial liquid was removed by saltwell jet pumping. The process of removing all supernatant and as much drainable liquid as possible is known as interim stabilization and was started in 1972 (Liverman 1975; Anderson 1990; WIDS).

The B/BX/BY complex tanks were interim stabilized beginning in 1975, with the interstitial liquid pumped to receiver tank 241-BX-104, and from there to the 242-S evaporator via the 241-ER-151 diversion box (later sent to the 242-A evaporator). The saltwell system for B/BX/BY farm included a pump pit for each tank, the saltwell and jet pump, underground piping from the pump pits to the receiver tank, and associated instrumentation and controls (Smith 1975; Grimes 1977).

AEC policy was to direct all liquid waste to double-shell tanks. To discontinue the use of a single-shell tank as the saltwell waste receiver, the 244-BX DCRT was constructed in 1983,

tying into the existing saltwell piping. See Figure 6 for an illustration of the saltwell system piping arrangement. The 244-BX is the only facility available to transfer waste to and from the B/BX/BY tank farms (Mirabella 1977; Hanson 1980; Hanlon 1999; WIDS).

Six tanks in the B/BX/BY complex were interim stabilized prior to construction of 244-BX. All tanks in the B/BX/BY complex are now interim stabilized, except 241-BY-105 and 241-BY-106 (Hanlon 1999).

Following interim stabilization, single-shell tanks were interim isolated by establishing at least one physical barrier between the tank contents and the environment, to preclude inadvertent addition of liquid. This was done by cutting and blanking all process piping to and from the tank, blanking all risers, and equipping the tank with a filtered ventilation system. The first tank to be isolated was 241-BX-102, in October 1980. Tanks B-101, BX-101, and BX-108 were isolated in 1982. The remaining tanks in B farm, and 241-BX-103, were isolated in 1985. All B and BX farm tanks are interim isolated. Seven BY farm tanks are interim isolated, and five tanks are partially interim isolated. The 244-BXR vault, the 241-B-301 catch tank, the 241-BX-302A catch tank, and all diversion boxes and transfer lines were isolated by project B-231 in 1984-1985 (Liverman 1975; Hanlon 1999; WIDS).

Three UPRs are associated with stabilization and isolation: one tank leak in 1976 (UPR-200-E-130), and two surface contamination incidents in 1978 (UPR-200-E-89) and 1985 (UPR-200-E-101). No UPRs have been recorded since 1985 (WIDS).

4.0 MONITORING TEST WELLS

Seven monitoring wells were originally drilled in each tank farm as part of original construction to check for tank leakage. To avoid groundwater contamination, these wells were drilled only to 49 m (150 ft) and did not extend to the upper aquifer (groundwater depth was 82 m [250 ft]). One well in 241-BY farm was drilled to 90 m (275 ft) as a groundwater monitoring well. Wells were checked weekly (Parker, 1944; Brown 1950). An extensive discussion of monitoring wells inside the tank farms is included in Gaddis (1999).

Knowledge of the groundwater hydrology of the Hanford area at time of initial construction was limited to a few reports from the 1910s and 1920s, all of which were general in scope and limited in content. The continuing need to dispose of 1C and 2C waste to the ground led the AEC to contract with the U.S. Geological Survey to drill a series of test wells in late 1946 to evaluate the 200 plateau soil for waste disposal suitability, and for general groundwater research. Three wells were drilled near the 216-B-7 cribs in May 1947. (Brown 1950).

An unusual structure is the Health Instruments shaft by the 216-B-8 crib. This shaft was constructed as part of the 1947-1949 expansion for collecting liquid and sediment samples. It is 18 m (55 ft) deep and consists of prefabricated concrete sections, 2.6 m (8 ft) in diameter, 2 m (6 ft) high, and 246 cm (9 in) thick. Steel laterals 164 cm (6 in) in diameter and 7.2 m (22 ft) long are installed in holes in the walls of the concrete sections 3.3 m (10 ft) and 6.6 m (20 ft) below the crib and carefully emplaced to minimize disturbing the sediments. Openings in the

tops of the laterals permit liquid to enter and collect in sample cups. Other holes were made in the shaft wall facing the crib and covered with removable cups to enable collection of sediment samples. Liquid seepage into the shaft made it necessary to reduce the rate of discharge to the 216-B-8 crib. The shaft was later used as a run-in pit for contaminated pumps (H-2-738; Brown 1950).

Other monitoring wells were drilled near cribs to monitor vadose zone contamination. Wells were built for the BY cribs (1 per crib) as part of original construction. Additional test wells were drilled in 1966 at the BY cribs. In the early 1970s, additional wells were drilled around individual tanks to more closely monitor tank leakage. Other test wells were drilled to monitor groundwater contamination (Liverman 1975). An extensive discussion of monitoring wells is included in Gaddis (1999).

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APPENDIX 1: INTENTIONAL RELEASE QUANTITIES

Site Number	Location	Operation Dates	Source	Waste Type	Waste Volume (liters)	Comments
216-B-7A	241-B farm	9/46-12/54	224-B	224	4.3×10^7 (7A and 7B combined)	Radionuclide capacity reached
		10/47-8/48	221-B	5-6		
		12/54-9/58	224-B	Cleanout		
		12/54-10/61	221-B	5-6		
		10/61-5/67	221-B	Decon Waste		
216-B-7B		9/46-5/67	216-B-7A	Overflow		
216-B-8	241-B.farm	4/48-12/51	221-B	2C	2.72×10^7	
		7/51-12/51	221-B	5-6		
		12/51-12/52	224-B	Decon waste		
216-B-11A	241-B farm	12/51-12/54	242-B	1C condensate	2.96×10^7 (11A and 11B combined)	
216-B-11B			216-B-11A	Overflow		
216-B-35	BX trenches	2/54-3/54	221-B	1C	1.06×10^6	
216-B-36	BX trenches	3/54-4/54	221-B	1C	1.94×10^6	
216-B-37	BX trenches	8/54	242-B	1C Bottoms	4.32×10^6	
216-B-38	BX trenches	7/54-8/54	221-B	1C	1.43×10^6	
216-B-39	BX trenches	12/53-11/54	221-B	1C	1.47×10^6	
216-B-40	BX trenches	4/54-7/54	221-B	1C	1.64×10^6	
216-B-41	BX trenches	11/54	221-B	1C	1.44×10^6	
216-B-42	BX trenches	1/55-2/55	221-U	TBP (PFeCN)	1.5×10^6	
216-B-43	BY cribs	11/54	221-U	TBP	2.1×10^6	Contaminated by UPR-200-E-9 in 1955
216-B-44	BY cribs	11/54-3/55	221-U	TBP	5.6×10^6	
216-B-45	BY cribs	4/55-6/55	221-U	TBP	4.9×10^6	
216-B-46	BY cribs	9/55-12/55	221-U	TBP	6.7×10^6	
216-B-47	BY cribs	9/55	221-U	TBP	3.7×10^6	
216-B-48	BY cribs	11/55	221-U	TBP	4.1×10^6	
216-B-49	BY cribs	11/55-12/55	221-U	TBP	6.7×10^6	
216-B-50	BY cribs	1/65-1/74	ITS#1	Condensate	5.9×10^7	
216-B-51	NE of 241-B	1/56-1/58	BC crib line	Flush drainage		
216-B-57	W of 241-BY	2/68-6/73	ITS#2	Condensate	8.4×10^7	
216-B-61	NW of 241-BY	Built 1969	ITS#2	None	None	Never used

APPENDIX 2: UNPLANNED RELEASE QUANTITIES

Site Number	Location	Date	Leak Type	Waste Type	Waste Volume (liters)	Comments
UPR-200-E-4	241-B-151	Fall 1951	Diversion Box Leak	MW		
UPR-200-E-5	241-BX-102	3/20/1951	Plugged Cascade Outlet	MW	346,700	
UPR-200-E-6	241-B-153	1954	Diversion Box Leak			
UPR-200-E-9	216-BY-201	9/15/1955	Tank Overflow	TBP	41,600	
UPR-200-E-38	241-B-152	1/4/1968	Diversion Box Leak			
UPR-200-E-43	Road near BY farm	1/10/1972	Spill From Truck			
UPR-200-E-73 (UN-216-E-1)	241-B-151	1951	Diversion Box Leak	MW		
UPR-200-E-74 (UN-216-E-2)	241-B-152	Spring 1954	Diversion Box Leak			
UPR-200-E-75 (UN-216-E-3)	241-B-153	1954	Diversion Box Leak			
UPR-200-E-76 (UN-216-E-4)	241-B-153	1/4/1968	Piping Leak	B Plant 9-2 Tank	20,441	
UPR-200-E-79 (UN-216-E-7)	Between 242-B and 207-B	June 1953	Underground Piping Leak	Cooling Water		
UPR-200-E-89 (UN-216-E-17)	BY cribs	1978	Surface Contamination			
UPR-200-E-101 (UN-216-E-30)	242-B	1985	Surface Contamination			
UPR-200-E-105	241-BY-107	12/16/1952	Overground Piping Leak	1C	87,000	
UPR-200-E-108	241-B-102	4/14/1953	Overground Piping Leak	MW		
UPR-200-E-109	241-B-104	11/11/1953	Riser Leak	TBP	568	
UPR-200-E-110	241-BY-112	8/7/1955	Valve Pit Leak	MW		
UPR-200-E-116	241-BY-112	11/20/1972	Piping Leak	Flush Water		
UPR-200-E-127	241-B-107	1968	Tank Leak		30,300	
UPR-200-E-128	241-B-110	1969	Tank Leak		31,500	
UPR-200-E-129	241-B-201	1968	Tank Leak		4,500	
UPR-200-E-130	241-B-203	1977	Tank Leak		1,135	
UPR-200-E-131	241-BX-102	1971	Tank Leak		265,000	
UPR-200-E-132	241-BX-102	1974	Tank Leak		9,500	
UPR-200-E-133	241-BX-108	1974	Tank Leak		9,500	
UPR-200-E-134	241-BY-103	1973	Tank Leak		19,000	
UPR-200-E-135	241-BY-108	1972	Tank Leak		19,000	

APPENDIX 3: HISTORICAL TIME LINE OF EVENTS

1943-1944:	Construction of B Plant and B Farm
Apr 13 1945:	B Plant begins operations. MW, 1C, 2C from B Plant discharged to B Farm.
Aug 11 1945:	WWII ends
Sep 1946:	216-B-7A&B cribs begin operation (B Plant 224 waste, via 241-B-201)
Jan 1 1947:	Control of Hanford Site shifts from U.S. Army Corps of Engineers to Atomic Energy Commission
Jan 1 1947:	General Electric replaces DuPont as Hanford prime contractor.
Aug 1947:	Large construction effort. B-8 crib, BX & BY farms, UR facilities, other
Jan 1948:	MW and 1C from B-Plant operations discharged to BX farm
Feb 1948:	2C from B Farm to 216-B-8 crib
Mar 1950:	MW and 1C discharged to BY farm
Mar 20 1951:	UPR-200-E-5, underground cascade piping MW leak at 241-BX-102
Jul 1951:	B Plant 5-6 waste sent to 216-B-8 crib
Mid-1951:	Continuous overflow from 241-B-112 to 216-B-8
Fall 1951:	UPR-200-E-4, diversion box MW leak at 241-B-151
Dec 1951:	Finish 2C discharge to 216-B-8; isolate crib
Dec 14 1951:	1C to 242-B: condensate to 216-B-11 reverse wells, cooling water to 207-B, bottoms to tank farms
1951-1952:	UPR-200-E-73 (UN-216-E-1), diversion box MW leak at 241-B-151
Oct 1952:	B Plant shut down
Nov 1952:	MW from B, BX, BY Farms pumped to U plant for uranium recovery (via BXR vault)
Dec 1952:	UPR-200E-105, overground piping 1C leak at 241-BY-107
Apr 14 1953:	UPR-200-E-108, overground MW leak at 241-B-102
Jun 1953:	UPR-200-E-79 (UN-216-E-7), underground pipeline cooling water leak between 242-B and 207-B
Sep 20 1953	TBP waste sent to 242-B for evaporation
Nov 11 1953:	UPR-200-E-109, riser TBP leak at 241-B-104
Dec 1953:	1C first discharged to BX trenches
1954:	UPR-200-E-6, diversion box leak at 241-B-153
Spring 1954:	UPR-200-E-74 (UN-216-E-2), diversion box leak at 241-B-152
Aug 1954:	Evaporator bottoms from 242-B to 216-B-37
Sep 1954:	Begin TBP scavenging in U Plant
Nov 1954	Finish 1C discharge to BX trenches
Nov 1954:	Scavenged TBP from U Plant to BY cribs
Nov 1954:	242-B shutdown; isolate 216-B-11A&B wells
1954-1955:	UPR-200-E-75 (UN-216-E-3), diversion box leak at 241-B-153
Jan 1955:	Scavenged TBP from U Plant to 216-B-42 trench
May 1955:	Groundwater contamination noted at 216-B-8 crib
Aug 1955:	Groundwater contamination noted beneath BY cribs
Aug 7 1955:	UPR-200-E-110, valve pit MW leak at 241-BY-112
Sep 15 1955:	UPR-200-E-9, flush tank TBP overflow at 216-BY-201 (within UPR-200-E-89)
Oct 1955:	Groundwater contamination noted at 216-B-42 trench
Nov 1955:	Begin TBP scavenging in 244-CR vault

Dec 1955:	Cs-137 detected in groundwater under BY cribs: TBP discharge rerouted to BC cribs instead
Jan 1956:	Scavenged TBP from line flush to 216-B-51 French drain
Feb 28 1956:	Co-60 detected under BY cribs at well E33-4, 100 times over limit
Jan 1 1958:	UR project completed
Mar 1965:	ITS#1 begins in BY farm; condensate to 216-B-50, cooling water to 207-B
May 1967:	Isolate 216-B-7A&B cribs
1968:	B Plant restarted for waste fractionization.
Jan 4 1968:	UPR-200-E-38, diversion box leak at 241-B-152
Jan 4 1968:	UPR-200-E-76 (UN-216-E-4), underground line leak at 241-B-153
Feb 1968:	ITS#2 begins in BY farm; condensate to 216-B-57, cooling water to 207-B
1968:	UPR-200-E-127, tank leak at 241-B-107
1968:	UPR-200-E-129, tank leak at 241-B-201
1969:	UPR-200-E-128, tank leak at 241-B-110
1971:	UPR-200-E-131tank leak at 241-BX-102
Aug 24 1971:	ITS#1 converted to cooler for ITS#2
Jan 10 1972:	UPR-200-E-43, truck spill on road near BY farm
1972:	UPR-200-E-135, tank leak at 241-BY-108
Nov 20 1972:	UPR-200-E-116, flush water spill at 241-BY-112
May 1973:	UPR-200-E-134, tank leak at 241-BY-103
1974:	UPR-200-E-132, tank leak at 241-BX-102
1974:	UPR-200-E-133, tank leak at 241-BX-108
Jun 30 1974:	ITS units shut down
1975:	Begin interim stabilization of B/BX/BY complex
Apr 1976:	UPR-200-E-130, tank leak at 241-B-203
1978:	UPR-200-E-89 (UN-216-E-17), surface contamination at BY cribs, spread by wind
1978:	Waste fractionization in B Plant discontinued.
Oct 1980:	Begin interim isolation of B/BX/BY complex
1983:	Construct 244-BX DCRT
1984:	Isolation of most diversion boxes
1985:	Isolation of catch tanks, BXR vault, B farm SSTs
Feb 1985:	B Plant permanently shut down
Aug 1985:	UPR-200-E-101 (UN-216-E-30), surface contamination at 242-B

APPENDIX 4: GLOSSARY

Crib: An underground liquid waste disposal facility filled with soil and/or crushed gravel utilizing the ion exchange properties to remove radioactive contamination. Cribs were typically operated until contamination was observed in the groundwater beneath the crib.

Specific Retention Trench: An unlined excavation used for the disposal of a designated volume of low-level or intermediate-level radioactive waste. Liquid is retained in the trench soil and does not migrate to the groundwater.

Reverse Well: A buried vertical pipe with the lower end open or perforated to allow seepage of liquid waste into the ground.

French Drain: A buried horizontal pipe filled with rock, open-ended or perforated, for disposal of liquid waste by seepage into the ground.

Double-Contained Receiver Tank (DCRT): Facility consisting of a reinforced concrete structure containing a receiver tank for radioactive liquid waste, a pump pit, and a filter pit.

Interim Stabilization: The process of pumping all supernatant and as much drainable interstitial liquid as possible from a single-shell tank to minimize the volume of liquid available to leak into the ground.

Interim Isolation: The process of establishing at least one physical barrier to any credible source of liquid addition to a single-shell tank, or other facility such as a diversion box, and separating the tank atmosphere from the outside air by a filtered ventilation system.

APPENDIX 5: FIRST CYCLE WASTE DISPOSAL TO BX TRENCHES

FIRST CYCLE WASTE DISPOSAL TO BX TRENCHES										
Date	Trench	Tank	Gallons	Liters	Pu (g)	U (g)	β (Ci)	Cs (Ci)	Sr (Ci)	Sb (Ci)
12/1/53	B-39	BX-112	206250	7.81E05	1.38	2200	905	430	11.7	N/A
2/18/54	B-35	BX-110	254380	9.63E05	0.48	1330	500	558	1.8	26
4/27/54	B-36	BX-111	467500	1.77E06	0.32	1270	1030	1010	6.2	N/A
7/17/54	B-38	BY-110	397375	1.50E06	1.20	45000	3000	6.3	1850	N/A
8/54	B-40	BY-110	298375	1.13E06	0.90	34000	1040	2.4	280	N/A
10/54	B-39	BY-106	200793	7.60E05	0.13	3990	350	450	0.38	44
10/54	B-41	BY-106	398943	1.51E06	0.24	7940	700	890	0.76	88
11/1/54	B-40	BY-106	154822	5.86E05	0.10	3080	270	350	0.29	34

Curies are 1955 values; uncorrected for decay.

There is a discrepancy regarding the dates of the 241-BY-106 discharges. Paas and Heid (1955) give dates of 11/1/54 for the discharges to 216-B-39 and 216-B-41 and 4/1/54 for the discharge to 216-B-40. The tank farm weekly summary (Bradley 1954) for the week of 10/22/54 to 10/29/54 describes a discharge of 500,000 gal from BY-106 to the trench; and for the week of 10/29/54 to 11/5/54 describes a discharge of 250,000 gal, which is also described as the final first-cycle waste transfer. The above dates are based on Bradley (1954) and are believed to be correct.

There is also a discrepancy regarding the volumes of the BY-106 discharges, although the total amount is not in dispute. Bradley describes the discharges as 500,000 gallons the first week and 250,000 the second. Paas and Heid describe the discharges as 600,000 gallons the first week and 150,000 the second. The above volumes are taken from Paas and Heid in order to retain the analytical data. The individual trench volumes differ slightly from Maxfield (1979) but agree within 10%.

FIRST CYCLE EVAPORATOR BOTTOMS DISPOSAL TO 216-B-37								
Date	Tank	Gallons	Liters	Pu (μCi/cc)	U (μCi/cc)	Cs (μCi/cc)	Sr (μCi/cc)	pH
8/1/54	B-109	1.30E05	4.92E05	2.38E-05	6.2E-07	0.82	3.7E-03	7.9
8/8/54	B-109	2.70E05	1.02E06	2.38E-05	6.2E-07	0.82	3.7E-03	7.9
8/31/54	B-107	3.20E05	1.21E06	2.38E-06	9.8E-07	0.82	7.4E-03	8.0
8/27-9/3	B-108	2.80E05	1.06E06	1.19E-05	2.7E-07	0.56	1.0E-03	8.1
9/3-9/10	B-108	2.50E05	9.46E05	1.19E-05	2.7E-07	0.56	1.0E-03	8.1
Totals		1.25E06	4.43E06	0.91 g	3750 g	3070 Ci	15.8 Ci	N/A

Curies are 1955 values; uncorrected for decay.

There is a discrepancy in the waste volumes for the 241-B-108 and 241-B-109 discharges. Bradley describes two discharges from B-109 totaling 400,000 gallons. Paas and Heid describe the total volume as 364,375 gallons. Bradley describes a discharge from B-107 and B-108 of 600,000 gallons and a second discharge from B-108 of 250,000 gallons. Paas and Heid describe the B-107 discharge as 320,375 gallons. If this is correct (and it agrees with the waste status summaries), the first B-108 discharge would be 280,000 gallons. The total for B-108 would then be 530,000 gallons. However, Paas and Heid describe the B-108 total as 449,625 gallons. Maxfield (1979) describes the total discharge to the trench as 4.32E06 L, which agrees within 10%.

APPENDIX 6: SCAVENGED TBP WASTE DISPOSAL TO BY CRIBS

Discharges of hundreds of thousands of gallons took several days to accomplish. Scavenging batch no. 4 was sent to specific retention trench 216-B-42 and not sampled. Batches 6, 8, and 9 were retained in the tanks and not cribbed. Batch 10 was cribbed but not sampled. Cs-137 contamination was found in the groundwater, and batches 21 through 30 were sent to the BC cribs. Disposal was halted after batch 30 when Co-60 contamination was discovered in the groundwater under the BY cribs. Subsequent batches were discharged to the BC specific retention trenches (Abrams, 1956).

SCAVENGED TBP WASTE DISPOSAL TO BY CRIBS										
Scavenging batch	1	2	3	4	5	7	10	11	12	13
To Crib	216-B-43	216-B-44	216-B-44	216-B-42	216-B-44	216-B-45	216-B-45	216-B-48	216-B-49	216-B-46
Date	11/6/54	12/10/54	12/22/54	2/13/55	3/8/55	4/5/55	6/17/55	11/2/55	12/7/55	8/29/55
Gallons	563,750	398,750	402,187	402,875	671,000	712,250	591,937	525,250	603,650	617,375
SAMPLE DATA				Not sampled			Not sampled			
Ph	N/A	8.9	9.0		10.0	9.4		9.3	8.9	9.9
Cs, µCi/mL	0.022	0.009	0.13		0.18	0.15		0.020	0.018	0.005
Sr, µCi/mL	0.63	1.13	0.22		0.27	0.83		0.39	0.73	0.54
Total β, µCi/mL	1.47	3.65	2.34		4.70	8.24		11.07	9.51	19.66
Total α, cpm/gal	50,000	80,000	20,000		1,100,000	900,000		300,000	500,000	1,200,000
PO_4, M	N/A	N/A	N/A		N/A	N/A		0.123	0.052	0.093
U, lb/gal	4.90	0.85	0.22		0.10	0.20		0.70	26.0	0.32
NO_3, lb/gal	N/A	N/A	N/A		N/A	N/A		1.76	1.82	0.96
Solids, wt. %	N/A	N/A	N/A		N/A	N/A		33.6	35.0	26.0
R.E., µCi/mL	0.75	1.49	0.22		0.25	1.57		0.25	1.72	0.93
Ce, µCi/mL	0.15	0.051	0.91		0.40	1.66		0.47	0.67	2.33
Zr-Nb, µCi/mL	N/A	0.31	0.24		0.46	1.33		1.05	0.59	0.05
Ru, µCi/mL	0.023	0.26	0.29		1.80	2.06		0.83	3.14	5.44
Sb, µCi/mL	0.009	0.23	0.33		0.07	0.31		0.38	0.39	0.69

Curies are 1955 values; uncorrected for decay.

N/A: not analyzed
R.E.: rare earth elements

SCAVENGED TBP WASTE DISPOSAL TO BY CRIBS

Scavenging batch	14		15		16		17		18		19		20					
To crib	216-B-47		216-B-47		216-B-46		216-B-48		216-B-49		216-B-49		216-B-46					
Date	9/21/55		9/28/55		10/18/55		11/2/55		11/25/55		12/12/55		12/21/55					
Gallons	569,250		403,560		591,250		555,500		591,250		552,750		572,000					
SAMPLE DATA																		
pH	10.1		9.2		9.4		9.5		10.5		9.95		9.65					
Cs, µCi/mL	0.071		0.020		0.024		0.19		0.15		0.015		0.027					
Sr, µCi/mL	0.19		0.12		0.14		0.22		0.32		0.077		0.045					
Total β, µCi/mL	12.52		11.62		13.87		18.10		23.22		16.20		14.79					
Total α, cpm/gal	400,000		400,000		400,000		300,000		400,000		500,000		300,000					
PO_4, M	0.125		0.104		0.131		0.164		0.096		0.145		0.126					
U, lb/gal	0.50		2.40		0.10		0.10		68.0		23.0		72.7					
NO_3, lb/gal	1.40		1.45		1.60		1.60		1.67		1.26		1.14					
Solids, wt. %	29.0		25.6		29.9		32.2		33.3		22.5		20.8					
R.E., µCi/mL	0.29		0.21		0.30		0.78		1.17		1.48		0.98					
Ce, µCi/mL	1.86		1.76		1.36		0.95		0.74		2.69		0.47					
Zr-Nb, µCi/mL	1.18		1.34		1.21		0.96		2.02		2.85		3.01					
Ru, µCi/mL	5.60		4.07		1.30		2.39		1.47		6.26		5.49					
Sb, µCi/mL	0.79		0.65		0.40		0.59		0.49		0.91		0.71					

Curies are 1955 values; uncorrected for decay.

N/A: not analyzed
R.E.: rare earth elements

Figure A-1. Manhattan Project, 1943 through 1945 (adapted from Williams 1999).

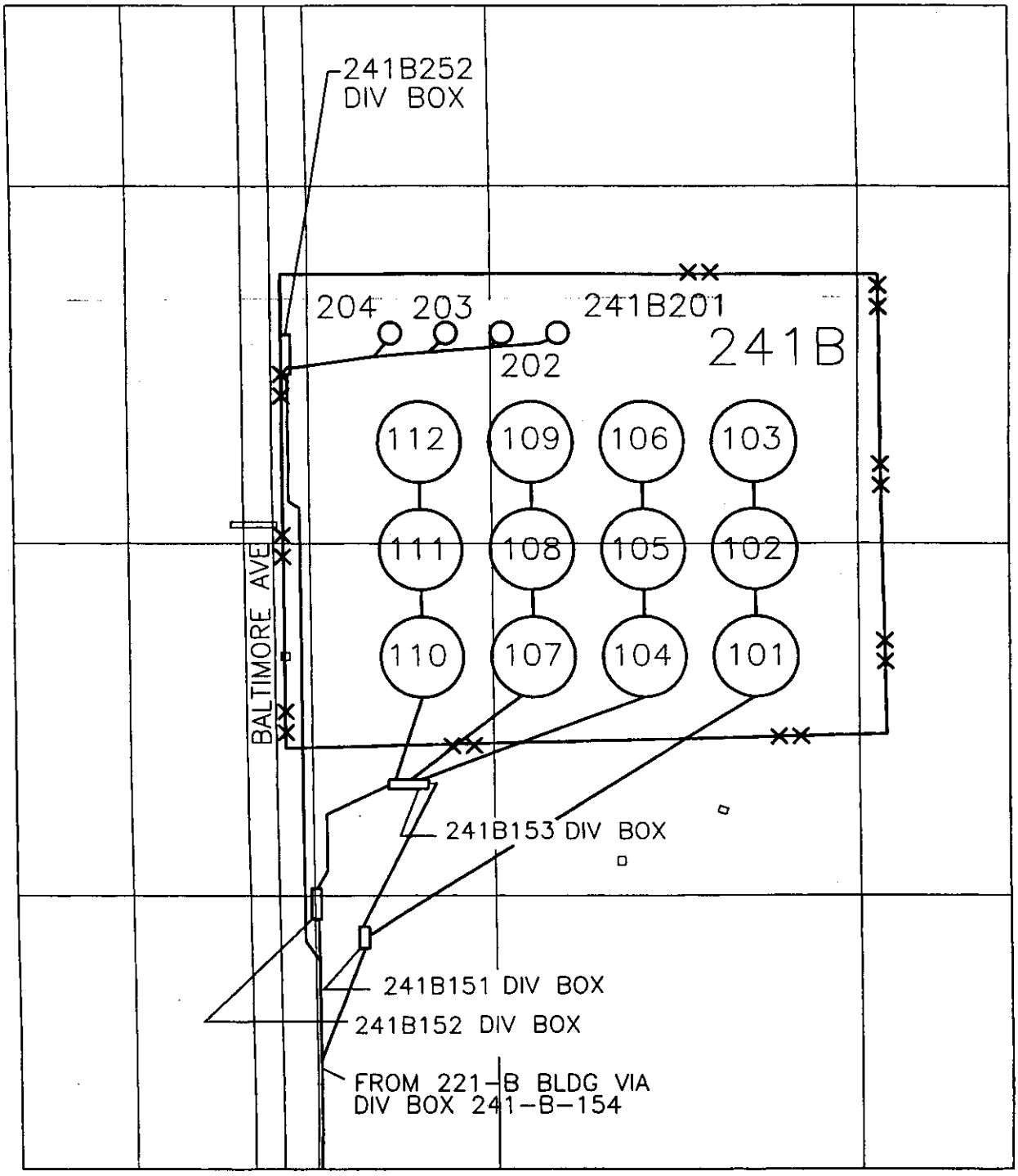


Figure A-2. Post-War Bismuth Phospate Operations, 1946 through 1953 (adapted from Williams 1999).

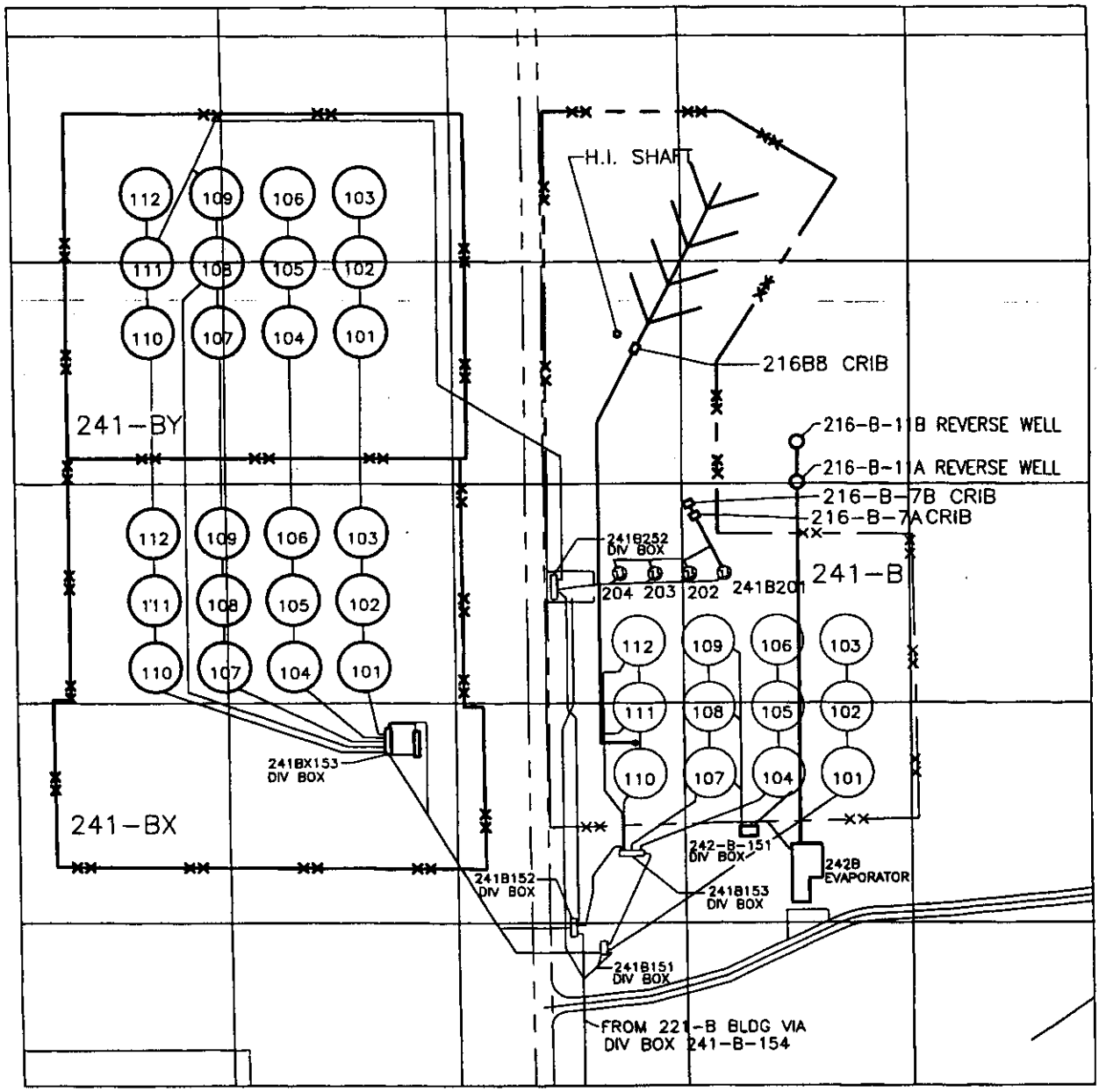


Figure A-3. Uranium Recovery Operations, 1954 through 1958 (adapted from Williams 1999).

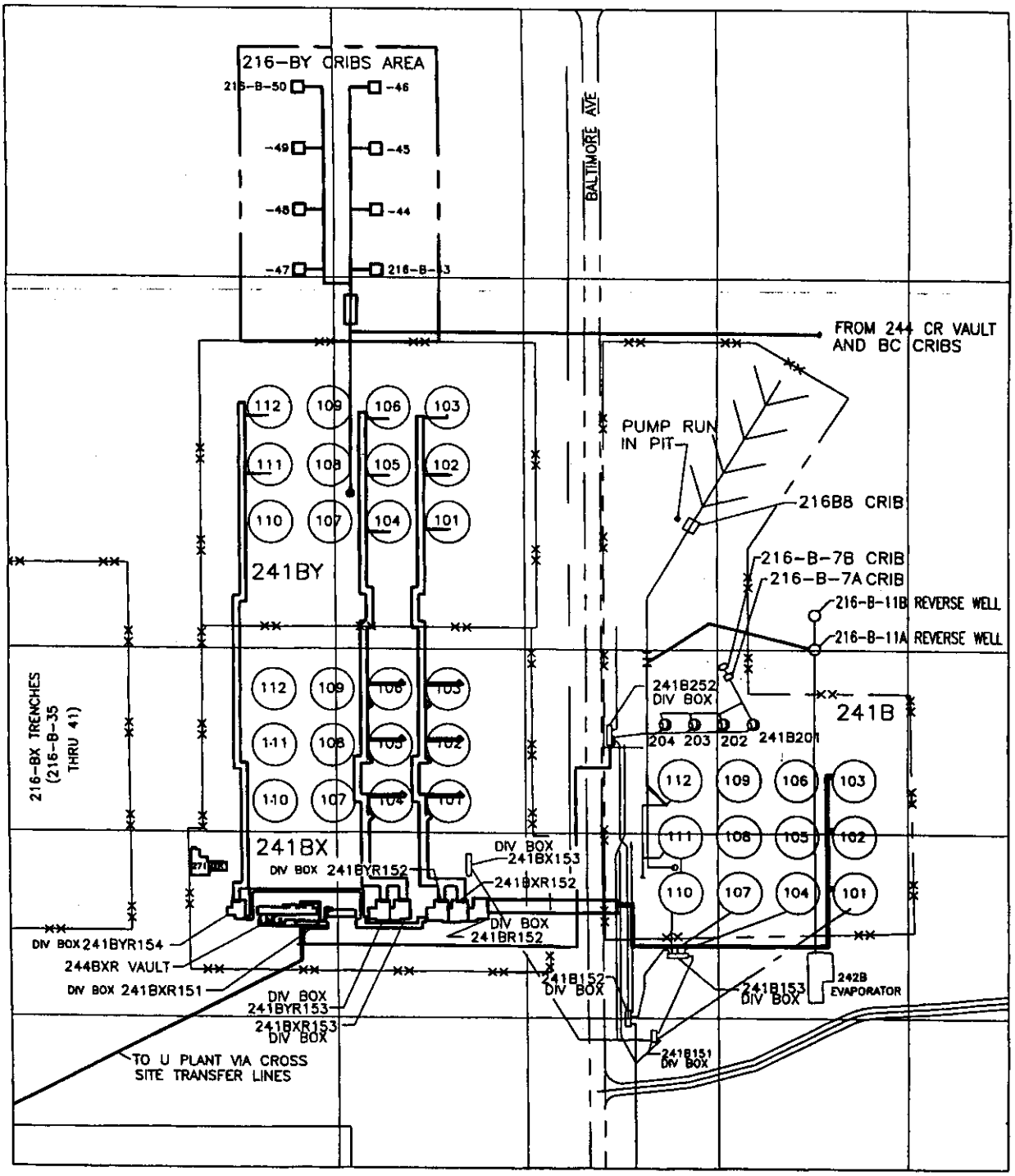


Figure A-4. In-Tank Solidification Operations, 1965 through 1975 (adapted from Williams 1999).

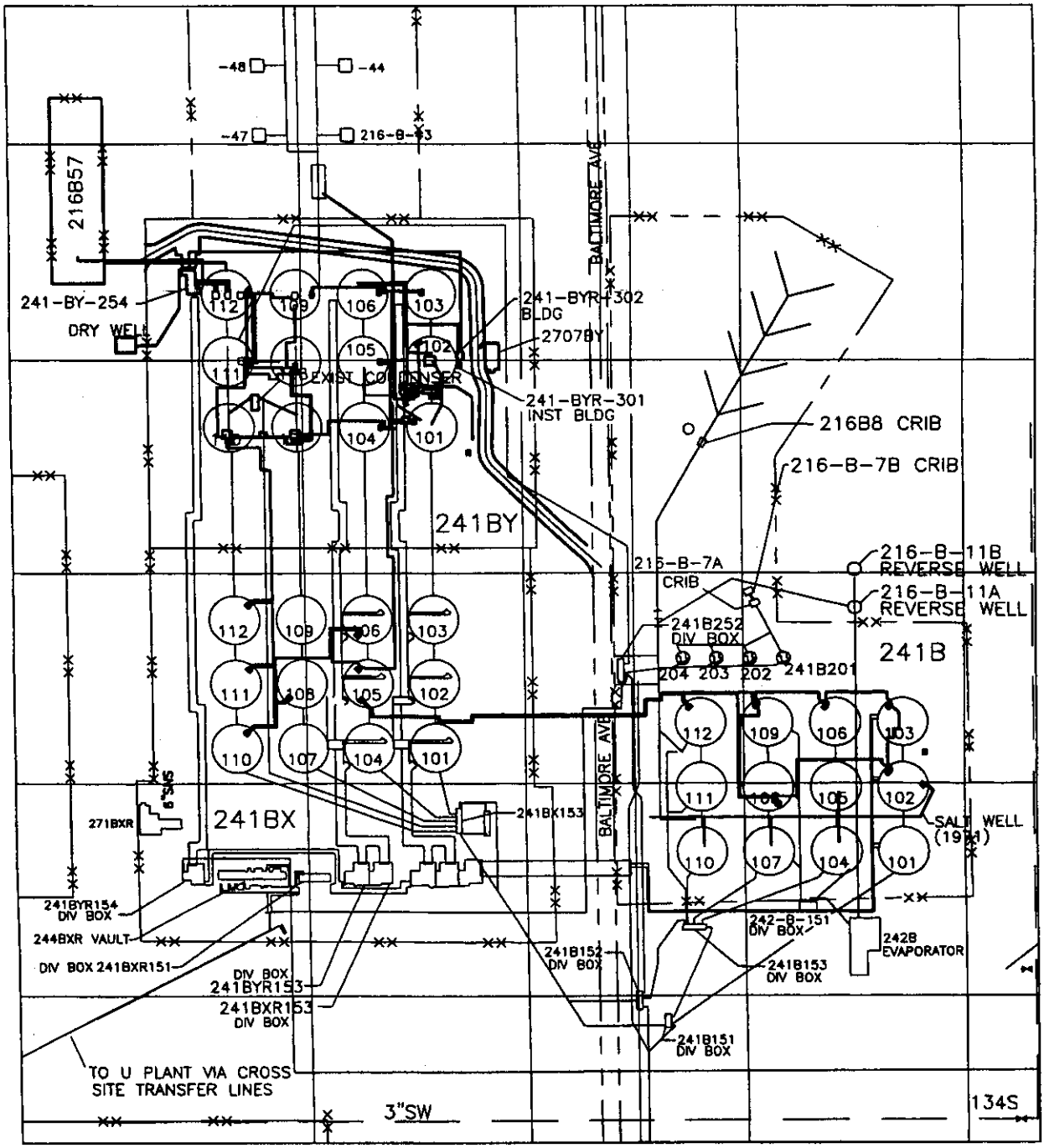
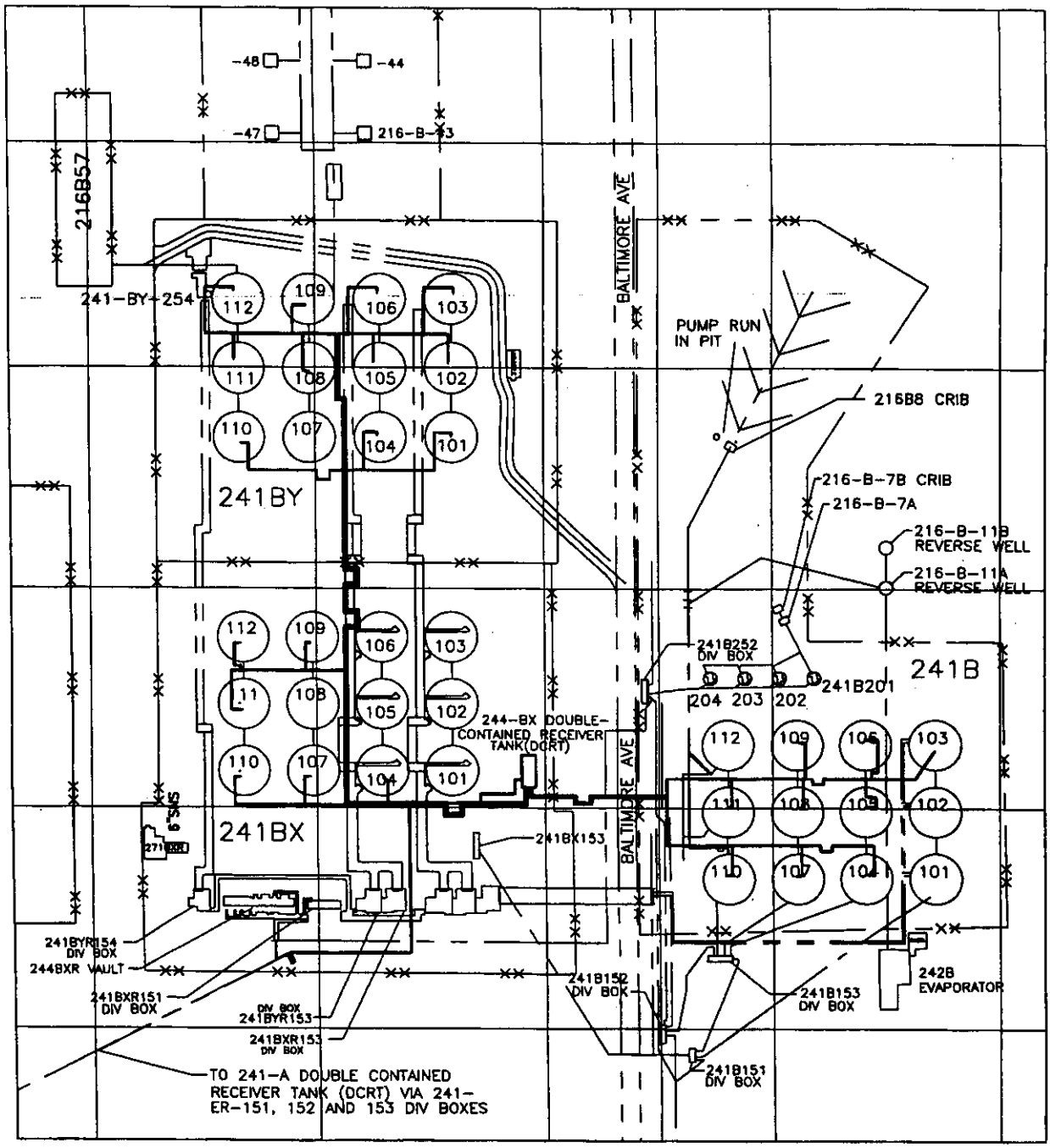


Figure A-5. Tank Stabilization (Salt Well Pumping), 1975 to Present (adapted from Williams 1999).



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HANFORD WORKS MONTHLY REPORT

FOR

FEBRUARY 1951

Compiled By
Division Managers

March 20, 1951

HANFORD WORKS
RICHLAND, WASHINGTON

36545

Classification Cancelled (Change to Declassified with Deletions
By Authority of RLO-CG-4
WA Snyder 2/12/92
DJ Fisher 2/12/92
PM Eick 2-12-92

Classification reviewed for declassification but left unchanged
by J. L. Brown
by M. Walker
Date 5/12/73

Operated for the Atomic Energy Commission
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Route To	Read By	Date	Route To	Read By	Date
H. B. Lindberg 61018 / 321KO	Jeo.	JAN 1 8 1974			
MC Fraser 62053 / 421CO	4/10-7 / 2-13-7 / 222-B	FEB 5 1974			
SL Gydesen, PNL	1/28/92				

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c. Acid Washes - B and T Plants

An acid wash was completed through one parallel line of the Canyon Building and through the Concentration Building at both B and T Plants with no abnormal recoveries being effected. The following data detail as percentages of standard charges the product recovery by the regular acid washes and Concentration Building pre-flushes:

Run	Extraction	Sect. 12 & 1st Cycle	2nd Cycle	221 Bldg.	224 Bldg.	Total thru Process	Preflush B E&F Cells
B-11-01-AW-1	6.19	15.48	12.09	33.76	11.94	45.70	22.71
T-11-02-AW-1	7.29	8.09	12.86	28.24	-1.91	26.33	27.30

d. Depleted Uranium Loss - B Plant

At the beginning of the month the depleted Uranium from B Plant extraction was being stored in the 103-BY underground storage tank after cascading through the 101-BX series and thence to the 101-BY series. On February 9 it was found that the level in the 103-BY tank was not rising, making it apparent that either a leak existed in the lines to the tank farms or that one of the cascade lines between the intervening tanks from 101-BX to 103-BY was plugged. Measurements of the levels existing in each tank of the two series were made, and it was found that the level in the 102-BX tank had risen above the normal cascade overflow point of 16 feet, indicating a plug in the effluent line. The level in the 102-BX tank was permitted to rise to 17 feet, one foot below the top of the steel inner shell in the hope that the head would break the plug, before the depleted uranium was diverted to another series of tanks. This was done on February 20. A few days after the diversion to another series of tanks was made, the level in the 102-BX tank was observed to be dropping slowly while the level in the succeeding tanks in the series and the 103-BY tanks remained essentially the same. A day later radiation determinations in the 150 feet deep dry well near the 102-BX tank were positive. By this time the level in the 102-BX tank had decreased approximately six inches. A special jet assembly was fabricated, installed in the 102-BX tank and the supernatant jetted to the 103-BX tank until the level in the former was 15 feet, 9 inches. Very close daily checks will be maintained of this level until it is certain that the leak is not in a region below the tank nozzles.

A review of the tank inventories versus the amount of depleted uranium discharged to the 101-BX - 101-BY series tanks indicates that approximately 91,600 gallons of supernatant

Classification Cancelled (Change to UNCLASSIFIED)
By Authority of RL-CG-1
Topa 4.4.2
By A.C. Bruce 1-5-74

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s Division

containing an estimated 22.5 tons of depleted uranium were lost to the soil in the vicinity of the 102-BX tank. Although the location of the leak point is not known, it now seems most likely that it was either at one or more of four spare nozzles on the tanks which are sealed with asphalt and a metal cap over the end of the nozzle or at the inlet nozzle, which is an asbestos packed joint. All five of the above nozzles were submerged when the level in the tank was at its highest point.

3. <u>Process Control</u>

a. <u>Dissolver Off-Gas Filter (Project C-337) and Silver Reactor (Project C-378)</u>

A revised directive was received from the AEC to construct a fifth reactor filter assembly for possible replacement purposes. The procurement of materials for the fifth assembly is progressing satisfactorily.

New steam ejectors required for the four installations to increase the vacuum on the dissolvers have arrived; one unit will be modified to fit the present assembly, and tested before additional ejectors are installed.

b. <u>First Decontamination Cycle Waste Evaporator (Project C-369)</u>

The over-all construction phase of the project is proceeding satisfactorily with 74% completion at month end. Procurement of materials and equipment is essentially complete with early shipment dates promised on items not already delivered. The major equipment pieces were delivered to the job site late in the month and are being installed at month end.

The Project Proposal for the 200-E Area evaporator has been approved by the A & B Committee and submitted to the AEC for approval. Procurement of materials for this job, as authorized by Work Release ER#2554, dated 2-1-51, has been initiated.

c. <u>Cell Drain Conductivity Meters (Project C-397)</u>

All of the conductivity meter leak detection devices in 221-T and B Plants are in operating condition except for the one in Cell 7R in 221-T. This unit has been overhauled and is to be installed when operating time permits.

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DECLASSIFIED

Classification Cancelled (Change to UNCLASSIFIED)

By Authority of RL-CG-1

TGA 4-4-3

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APPENDIX B

SUPPORTING STRATIGRAPHIC INFORMATION

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APPENDIX B

SUPPORTING STRATIGRAPHIC INFORMATION

Appendix B provides the detailed stratigraphic cross sections used to construct the subsurface physical model of the B-BX-BY Waste Management Area. Figures B-1 through B-6 show five cross sections and a fence diagram of the B-BX-BY Waste Management Area. Figures B-7 and B-8 show regional groundwater plumes of hazardous and radioactive constituents.

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Figure B-1. Geologic Cross Section A-A'.

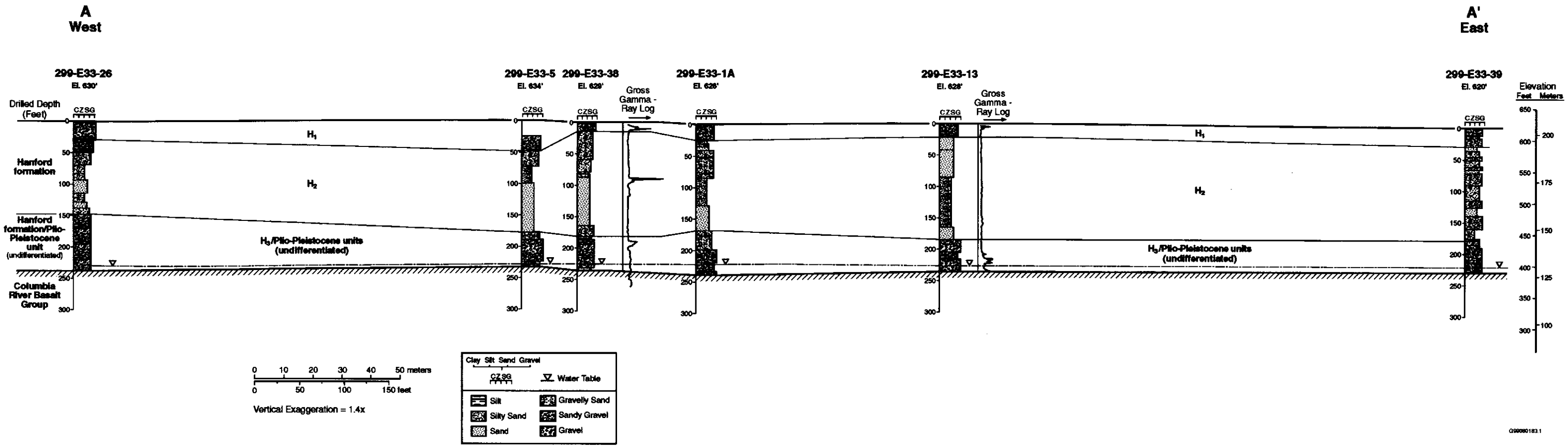

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Figure B-2. Geologic Cross Section B-B'.

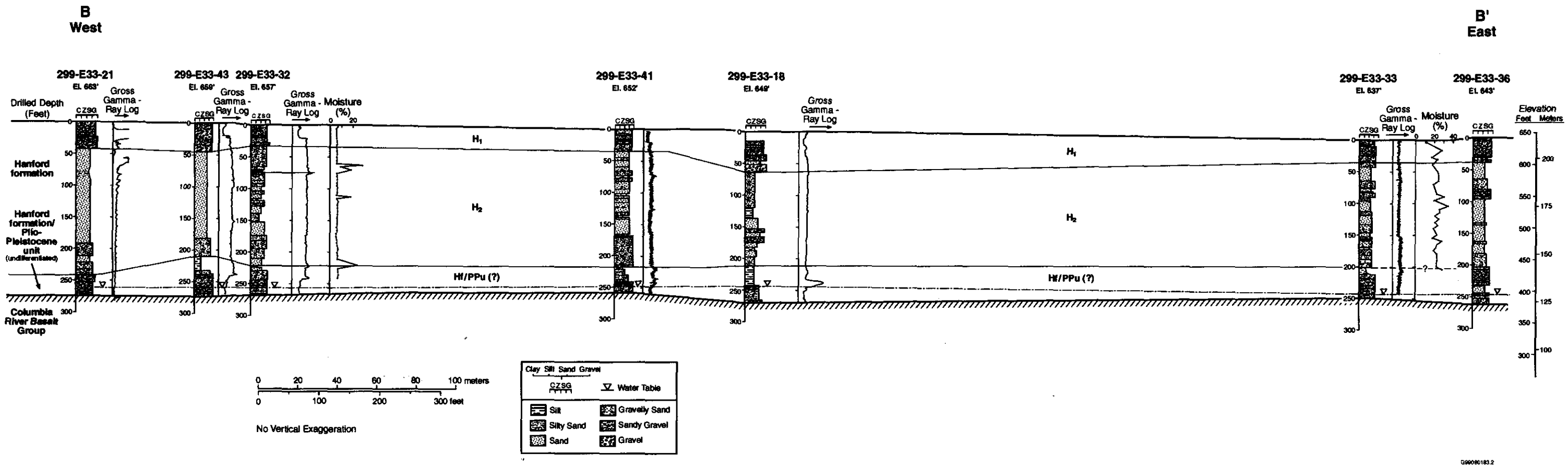

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Figure B-3. Geologic Cross Section C-C'.

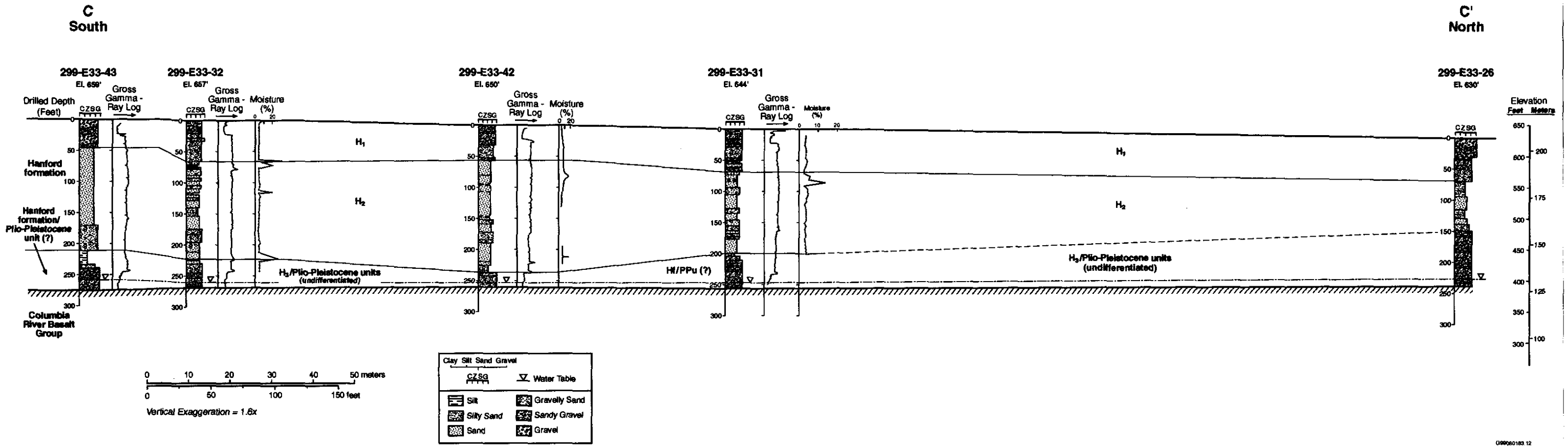

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Figure B-4. Geologic Cross Section D-D'.

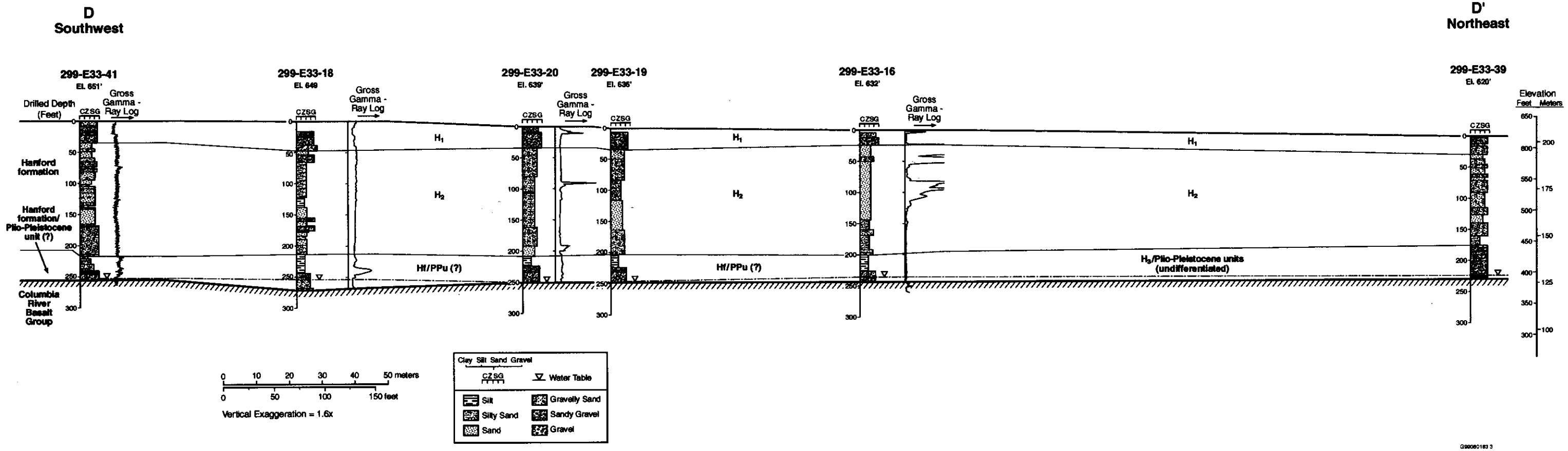

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Figure B-5. Geologic Cross-Section E-E'.

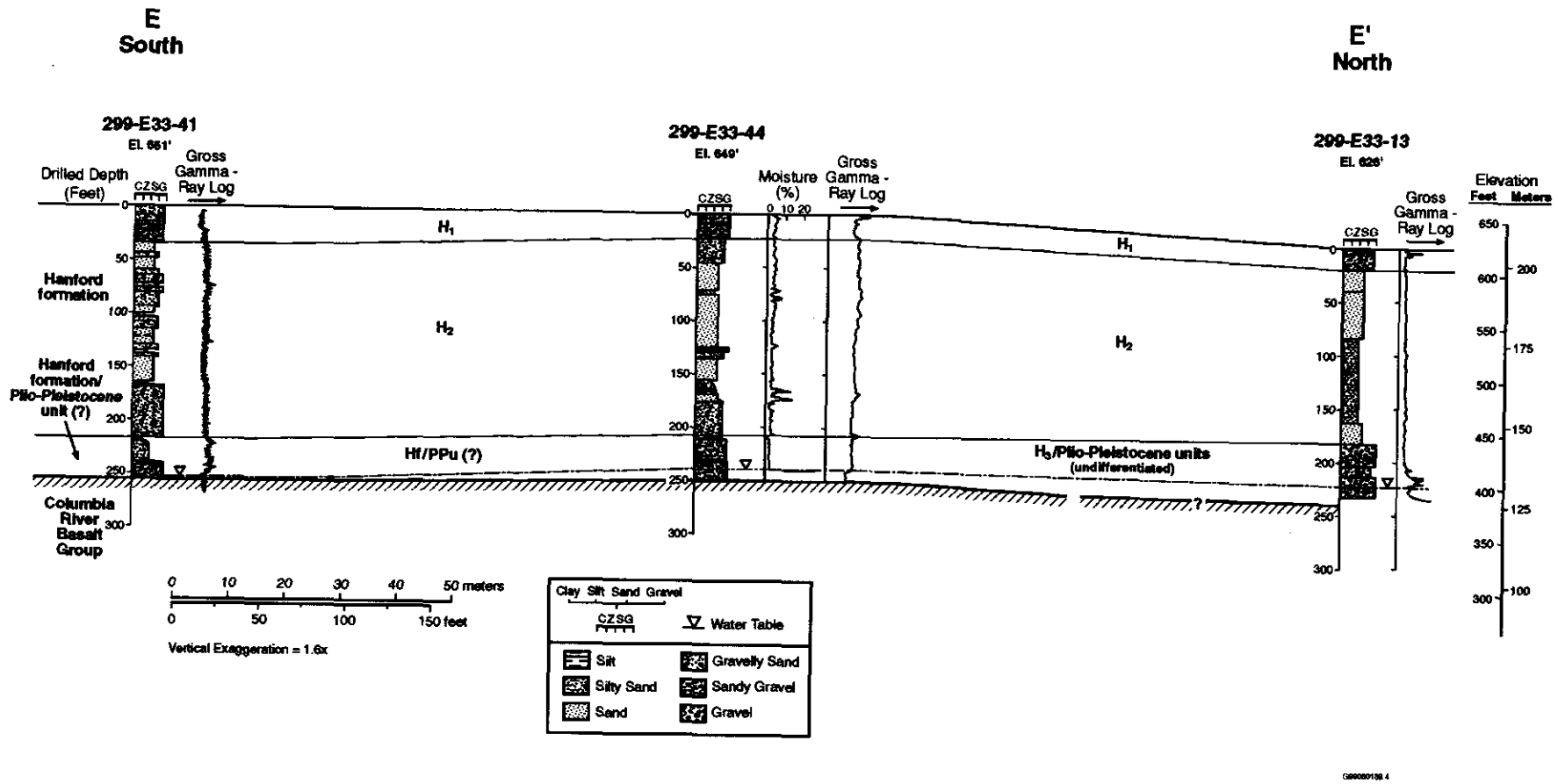

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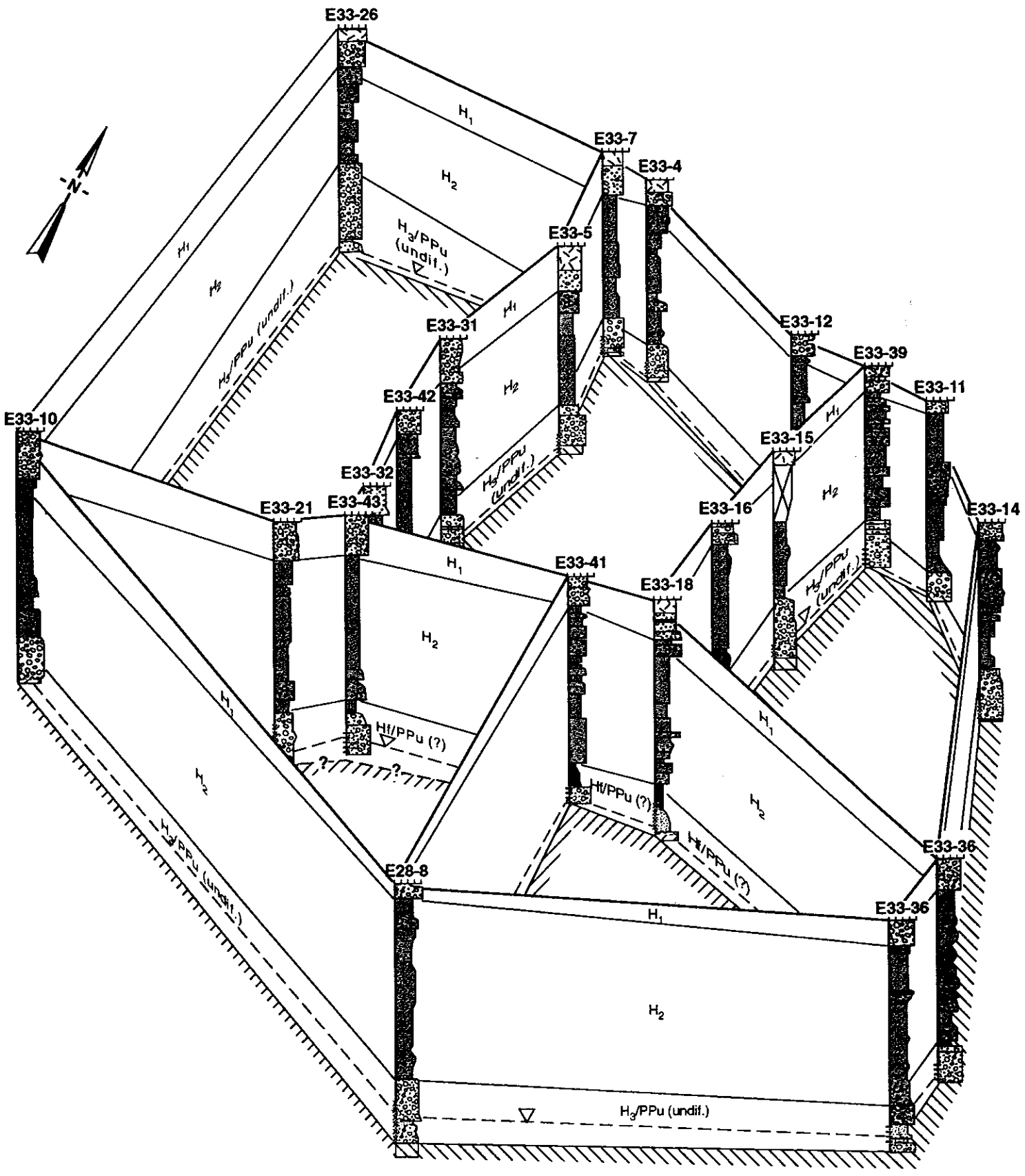
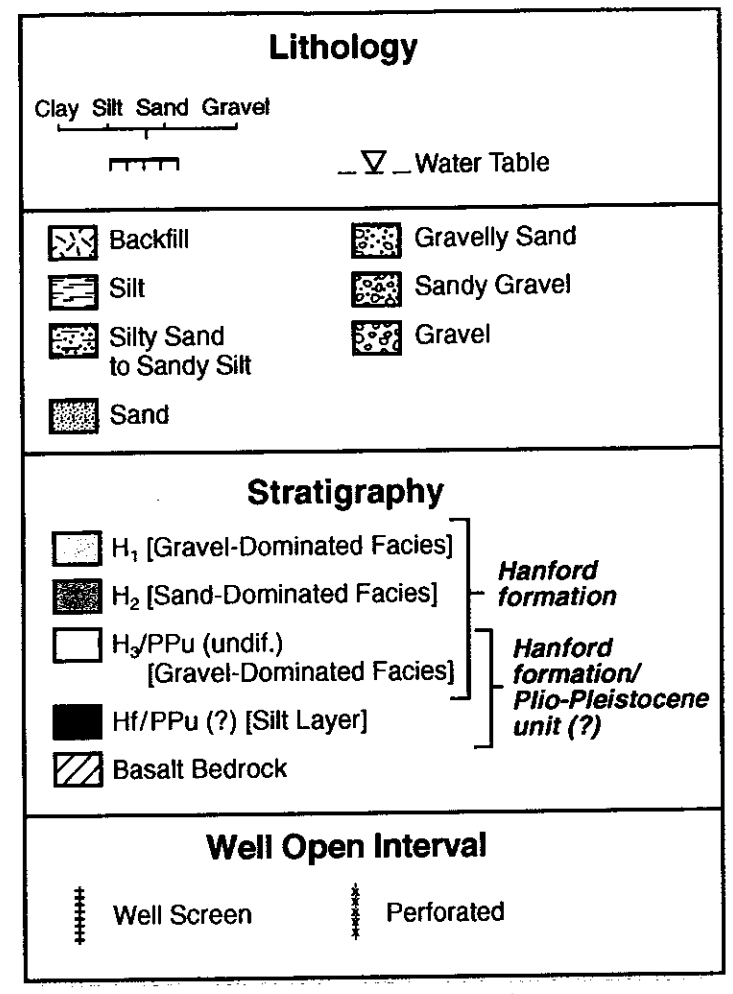
Figure B-6. Fence Diagram.





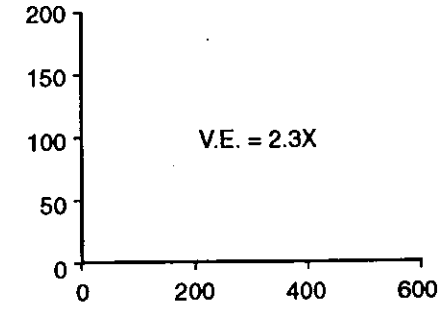


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Figure B-7. Regional Groundwater Plume of Hazardous Constituents.

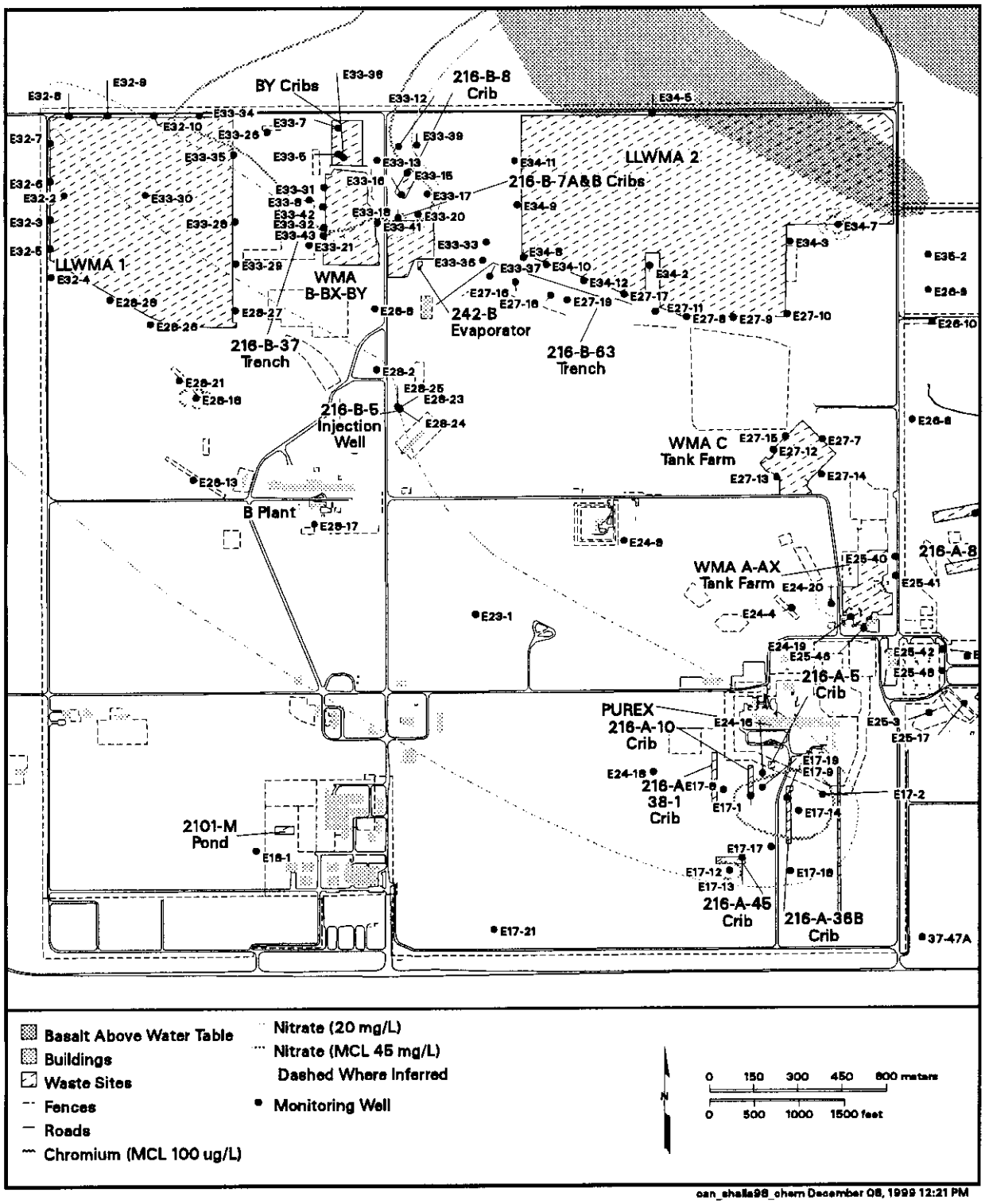


Figure B-8. Regional Groundwater Plume of Radioactive Constituents.

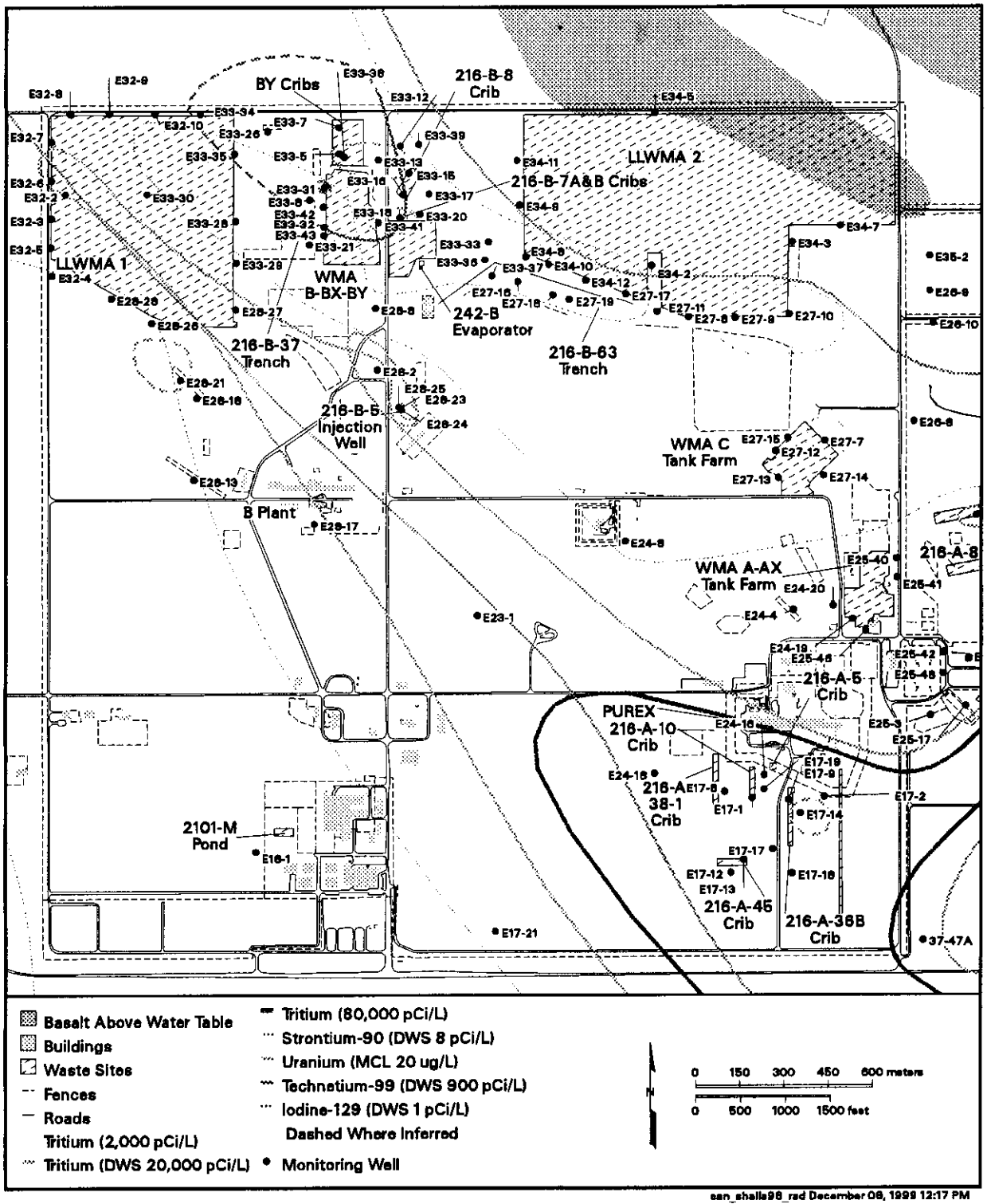
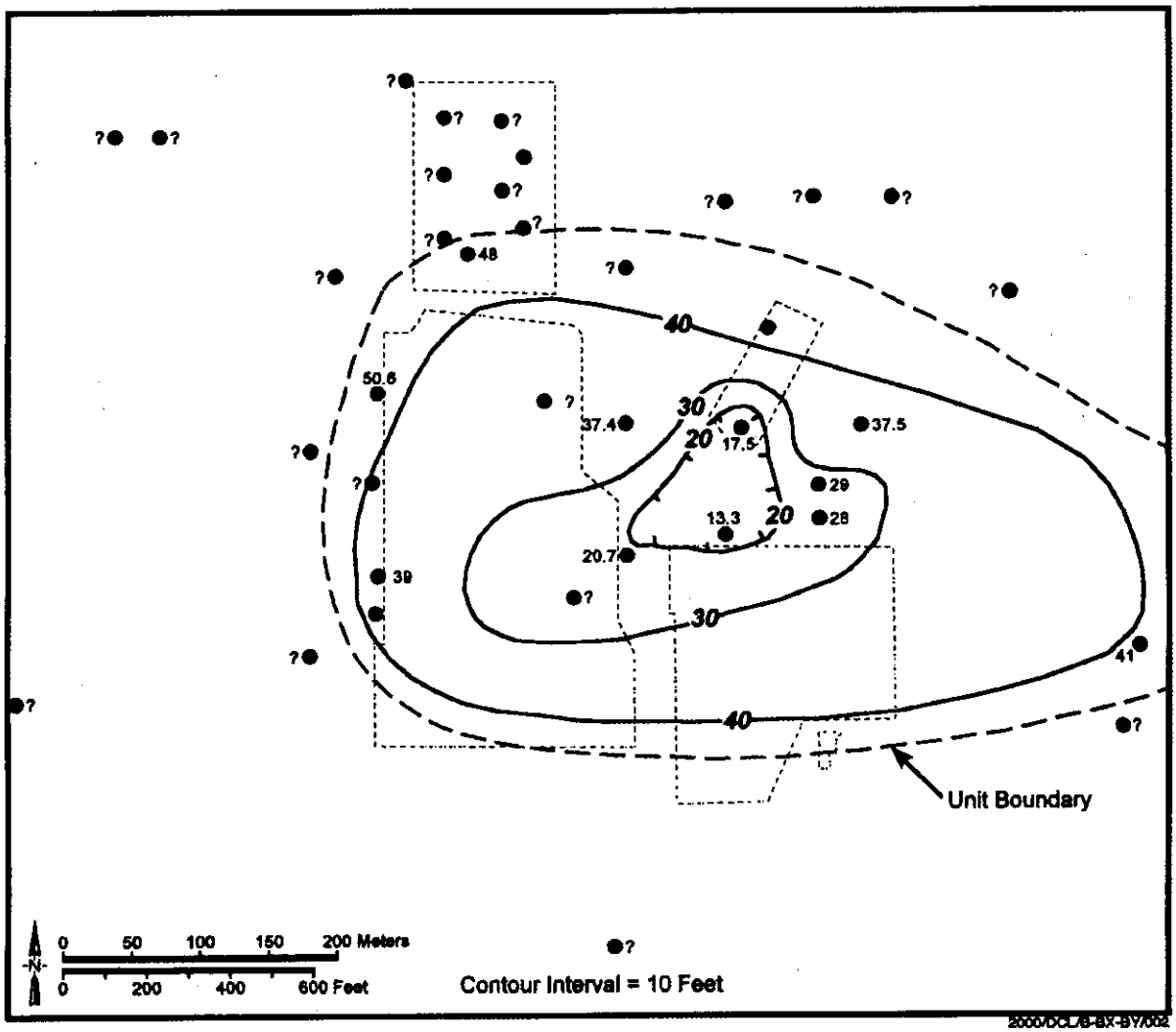


Figure B-9. Thickness of Hf/PPU (?) Gravel Facies.



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APPENDIX C

SUPPORTING METEOROLOGICAL AND HYDROLOGIC DATA

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APPENDIX C

SUPPORTING METEOROLOGIC AND HYDROLOGIC DATA

Table C-1 provides summary tables of monthly and annual precipitation at the Hanford Site from 1946 to 1998. Table C-2 summarizes the physical and hydrologic soil property data collected from soil samples in the 200 East Area.

Table C-1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1946	—	—	—	—	—	—	0.15	0.35	0.52	0.65	0.66	0.11	—
1947	0.32	0.27	0.42	0.70	0.02	1.07	0.71	0.68	1.34	2.20	0.81	0.75	9.29
1948	1.36	0.69	0.07	0.95	1.71	1.47	0.40	0.39	0.16	0.45	0.95	1.11	9.71
1949	0.13	0.68	1.12	0.02	0.16	0.01	0.01	0.03	0.23	0.10	1.47	0.16	4.12
1950	1.80	1.06	0.87	0.47	0.27	2.92	0.07	T	0.01	2.46	0.55	0.97	11.45
1951	0.84	0.51	0.46	0.53	0.43	1.38	0.37	0.15	0.10	0.71	0.82	0.70	7.00
1952	0.65	0.50	0.06	0.13	0.58	1.07	T	0.08	0.08	0.04	0.20	0.77	4.16
1953	2.16	0.25	0.17	0.77	0.28	0.55	T	0.96	0.13	0.20	0.96	0.49	6.92
1954	1.48	0.28	0.59	0.07	0.41	0.10	0.22	0.42	0.51	0.42	0.86	0.35	5.71
1955	0.56	0.22	0.17	0.40	0.59	0.28	0.57	0	0.77	0.40	1.54	2.03	7.53
1956	1.71	0.56	0.10	T	0.22	0.86	T	0.38	0.01	1.03	0.15	0.58	5.60
1957	0.48	0.23	1.86	0.38	0.82	0.47	0.05	0.02	0.34	2.72	0.39	0.53	8.29
1958	1.74	1.48	0.46	0.64	0.74	0.81	0.02	T	0.05	0.19	0.77	1.84	8.74
1959	2.05	1.17	0.40	0.20	0.50	0.23	T	0.03	1.26	0.56	0.41	0.26	7.07
1960	0.51	0.58	0.67	0.53	0.71	0.14	T	0.26	0.23	0.23	0.92	0.64	5.42
1961	0.33	2.10	1.02	0.48	0.80	0.42	0.15	0.09	T	0.07	0.49	0.89	6.84
1962	0.13	0.90	0.14	0.34	1.35	0.12	T	0.50	0.38	0.95	0.65	0.60	6.06
1963	0.95	0.69	0.53	1.17	0.43	0.28	0.31	0.01	0.02	0.04	0.74	1.14	6.31
1964	0.37	0.01	0.03	0.11	0.04	0.90	0.04	0.24	0.09	0.28	0.94	2.34	5.39
1965	0.93	0.14	0.03	0.09	0.15	0.49	0.11	0.03	0.11	0.01	1.17	0.39	3.65
1966	0.68	0.03	0.39	0.03	0.05	0.43	0.81	T	0.27	0.39	2.25	0.60	5.93
1967	0.32	T	0.14	0.90	0.56	0.57	T	T	0.05	0.13	0.16	0.43	3.26
1968	0.88	0.58	0.02	0.01	0.06	0.19	0.04	0.51	0.25	0.93	1.23	1.25	5.95
1969	1.24	0.54	0.10	1.22	0.51	0.75	T	T	0.48	0.10	0.13	1.29	6.36
1970	2.47	0.75	0.27	0.45	0.54	0.25	0.01	T	0.03	0.24	0.71	0.61	6.33
1971	0.78	0.10	1.02	0.07	0.56	0.71	0.13	0.09	1.13	0.18	0.46	1.07	6.30
1972	0.19	0.27	0.58	0.10	2.03	0.66	0.16	0.56	0.02	T	0.55	1.27	6.39
1973	0.90	0.21	0.08	T	0.24	0.01	T	0.02	0.43	1.72	2.64	2.02	8.27
1974	0.90	0.41	0.52	0.46	0.28	0.12	0.71	T	0.01	0.21	0.71	0.97	5.30
1975	1.43	0.98	0.33	0.42	0.38	0.24	0.32	1.16	0.03	0.87	0.60	0.70	7.46
1976	0.56	0.33	0.23	0.41	0.08	0.11	0.13	0.96	T	0.04	T	0.11	2.99
1977	0.08	0.57	0.41	T	0.65	0.37	0.06	1.36	0.66	0.15	0.63	1.47	6.41
1978	1.72	0.92	0.30	0.46	0.41	0.09	0.52	0.57	0.11	T	1.21	0.26	6.57
1979	0.54	0.17	0.54	0.52	0.10	T	0.09	0.38	0.20	0.67	1.36	0.99	5.56
1980	1.32	1.30	0.30	0.86	1.41	0.96	T	0.02	0.85	0.33	0.44	1.89	9.68
1981	0.56	0.60	0.70	0.02	0.99	0.43	0.19	0.03	0.60	0.39	1.08	1.45	7.04
1982	0.33	0.57	0.30	0.75	0.28	0.75	0.22	0.20	0.55	1.33	0.91	1.79	7.98
1983	1.44	1.36	1.00	0.42	0.52	0.68	0.31	0.12	0.46	0.52	2.12	2.12	11.07
1984	0.23	0.94	1.01	0.60	0.55	0.99	0.06	T	0.42	0.07	1.83	0.57	7.27
1985	0.34	0.82	0.36	0.01	0.12	0.15	0.12	0.01	0.63	0.46	1.24	0.84	5.10
1986	1.76	1.37	0.76	T	0.30	T	0.21	0.02	0.96	0.29	0.65	0.77	7.09
1987	0.80	0.19	1.05	0.14	0.17	0.11	0.50	0.07	0.01	T	0.40	1.63	5.07
1988	0.48	T	0.39	1.12	0.33	0.11	0.13	0	0.39	0.01	0.82	0.40	4.18
1989	0.21	1.67	1.56	0.84	0.59	0.01	0.01	0.26	0.02	0.42	1.04	0.29	6.92
1990	0.77	0.09	0.10	0.40	0.86	0.36	0.14	0.83	T	0.78	0.02	0.72	5.07

Table C-1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1991	0.33	0.19	1.12	0.45	0.49	1.44	0.29	0.07	0	0.53	1.44	0.40	6.75
1992	0.44	0.94	0.09	0.94	T	1.14	0.39	0.20	0.27	0.61	1.07	1.82	7.90
1993	1.30	1.17	0.67	0.71	0.60	0.12	1.76	0.24	0.04	0.09	0.19	0.94	7.83
1994	0.44	0.11	0.03	0.61	1.27	0.38	0.15	0.08	0.08	0.93	0.68	1.36	6.12
1995	2.14	0.69	0.95	1.54	0.79	0.77	0.34	0.07	0.79	0.87	1.04	2.32	12.31
1996	1.42	1.22	0.83	0.43	0.62	0.05	0.14	0.02	0.22	0.88	2.67	3.69	12.19
1997	1.51	0.25	0.70	0.33	0.33	0.46	0.19	0.06	0.32	0.92	1.01	0.31	6.39
1998	1.24	1.15	0.50	0.07	0.52	0.48	0.34	0.04	0.10	0.28	1.29	0.44	6.45
Avg	0.93	0.63	0.51	0.45	0.53	0.53	0.22	0.24	0.32	0.55	0.91	1.01	6.82
Norm	0.79	0.62	0.47	0.41	0.51	0.38	0.18	0.27	0.31	0.39	0.91	1.03	6.26

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	$Theta_r$	$Theta_s$	K_s (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									
200-BP-1[2,4]	1-0526	299-E33-38	1.9	47	18	8	27	0	sandy gravel (5)	Hanford gravel	0.0164	1.5448	0.0229	0.2144	2.00E-05	split spoon	Hoffman 1992
	1-0527	299-E33-38	15.1	42	50	8	0	0	sandy gravel (6)	Hanford gravel	0.0255	1.6222	0.015[f]	0.0773	5.70E-05	split spoon	Relyea 1995
	1-0528	299-E33-38	51.0	42	50	8	0	0	sandy gravel (6)	Hanford sand	0.0045	1.8509	0.0105	0.0746	5.00E-04	split spoon	"
	1-0529	299-E33-38	62.3	79	14	7	0	0	sandy gravel (6)	Hanford gravel	0.0026	1.4909	0.0000	0.0557	4.20E-03	split spoon	"
	1-0530	299-E33-38	57.1	0	60	35	5	0	sand (2)	Hanford sand	0.0123	1.6899	0.0098	0.2663	7.10E-05	split spoon	"
	1-0531	299-E33-38	57.9	—	—	N/A	—	—	sand (2)	Hanford sand	0.0017	1.8438	0.0400[f]	0.4863	2.10E-06	split spoon	"
	1-0550	299-E33-40	14.0	63	32	5	0	0	sandy gravel (6)	Hanford gravel	0.0037	1.4567	0.0000	0.0757	6.00E-04	split spoon	"
	1-1133	216-B-61A	4.1	76	13	11	0	0	sandy gravel (6)	Hanford gravel	0.0028	1.8847	0.0162	0.0781	1.80E-03	split spoon	"
	1-1134	216-B-61A	5.8	55	24	13	8	0	sandy gravel (5)	Hanford gravel	0.0034	1.6905	0.0322	0.1409	2.80E-03	split spoon	"
	1-1136	216-B-61A	7.0	68	20	12	0	0	sandy gravel (6)	Hanford gravel	0.0056	1.4945	0.0187	0.1043	4.00E-04	split spoon	"
	1-1137	216-B-61A	8.8	38	49	13	0	0	sandy gravel (5)	Hanford gravel	0.0139	1.4207	0.0210	0.1542	1.80E-05	split spoon	"
	2-2244	216-B-49A	26.5	1	49	48	2	0	sand (2)	Hanford sand	0.0135	2.0185	0.0270	0.2687	4.60E-05	split spoon	"
	2-2253	216-B-49A	35.5	2	85	13	0	0	sand (2)	Hanford sand	0.0205	1.7138	0.0308	0.2284	8.80E-05	split spoon	"
	2-2258	216-B-43A	41.3	1	84	15	0	0	sand (2)	Hanford sand	0.0373	1.7815	0.0271	0.2306	2.80E-05	split spoon	"
	2-2261	216-B-49A	48.6	12	76	12	0	0	gravelly sand (4)	Hanford sand	0.0410	1.6885	0.0303	0.2026	1.80E-04	split spoon	"
	2-2271	216-B-57A	60.5	50	28	14	6	2	sandy gravel (5)	Hanford gravel	0.0074	1.4319	0.0145	0.1636	1.40E-05	split spoon	"
	2-2283	216-B-57A	13.9	6	83	11	0	0	sand (2)	Hanford sand	0.0298	1.6757	0.0269	0.2005	2.10E-05	split spoon	"
	2-2286	216-B-49A	14.9	0	4	92	3	1	sand (2)	Hanford sand	0.0077	3.0137	0.0569	0.4721	6.30E-05	split spoon	"
	2-2289	216-B-43A	51.4	4	84	12	0	0	sand (2)	Hanford sand	0.0131	1.6351	0.0409	0.1968	1.30E-04	split spoon	"
	2-2294	216-B-43A	61.4	39	33	17	7	4	sandy gravel (5)	Hanford gravel	0.0051	1.4514	0.0066	0.2006	4.40E-05	split spoon	"
	2-2297	216-B-57A	65.4	80	20	0	0	0	sandy gravel (5)	Hanford gravel	0.0059	1.8562	0.0074	0.0641	4.10E-04	split spoon	"
Grout[1,5]	5A	299-E25-234	1.5	1	73	17	5	4	sand (2)	Eolian sand	0.1480	1.3087	0.0187	0.4131	5.73E-04	split spoon	Rockhold et al. 1993

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	$Theta_r$	$Theta_s$	K_s (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									
Grout[1,5] (cont.)	5B	299-E25-234	1.5						sand (2)	Eolian sand	0.0211	1.5360	0.0336	0.3367	5.73E-04	split spoon	"
	19A	299-E25-234	5.8	2	28	53	12	5	loamy sand (1)	Eolian sand	0.3870	1.2615	0.0461	0.4860	8.88E-04	split spoon	"
	19B	299-E25-234	5.8						loamy sand (1)	Eolian sand	0.2729	1.5326	0.0363	0.5026	8.88E-04	split spoon	"
	25A	299-E25-234	7.6	0	49	36	10	5	loamy sand (1)	Eolian sand	0.0473	2.0595	0.0539	0.4407	1.80E-03	split spoon	"
	25B	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0519	1.3421	0.0342	0.5228	1.80E-03	split spoon	"
	25C	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0287	1.3529	0.0280[f]	0.5062	1.80E-03	split spoon	"
	25D	299-E25-234	7.6						loamy sand (1)	Eolian sand	0.0700	1.8780	0.0800[f]	0.4822	1.80E-03	split spoon	"
	29A	299-E25-234	8.8	0	60	31	6	3	sand (2)	Eolian sand	0.2718	1.1928	0.0000	0.4341	2.41E-05	split spoon	"
	29B	299-E25-234	8.8						sand (2)	Eolian sand	0.1033	1.2242	0.0000	0.4387	2.41E-05	split spoon	"
	37A	299-E25-234	11.3	1	43	39	10	7	loamy sand (1)	Eolian sand	0.0775	1.2921	0.0703	0.5114	5.77E-04	split spoon	"
	37B	299-E25-234	11.3						loamy sand (1)	Eolian sand	0.0914	1.3319	0.0844	0.5304	5.77E-04	split spoon	"
	46A	299-E25-234	14	0	73	22	2	3	sand (2)	Hanford sand	0.2923	1.3658	0.0000	0.4581	2.99E-04	split spoon	"
	46B	299-E25-234	14						sand (2)	Hanford sand	0.0613	1.4343	0.0000	0.3708	2.99E-04	split spoon	"
	54A	299-E25-234	16.5	1	51	32	9	7	sand (2)	Hanford sand	0.1524	1.4137	0.0262	0.4488	1.38E-05	split spoon	"
	54B	299-E25-234	16.5						sand (2)	Hanford sand	0.1451	1.4419	0.0216	0.4543	1.38E-05	split spoon	"
	69A	299-E25-234	21	3	71	19	5	2	sand (2)	Hanford sand	0.3357	1.2658	0.0000	0.3721	1.21E-03	split spoon	"
	69B	299-E25-234	21						sand (2)	Hanford sand	0.2269	1.6572	0.0288	0.4042	1.21E-03	split spoon	"
	83A	299-E25-234	25.3	4	70	19	5	3	sand (2)	Hanford sand	0.2979	1.3300	0.0070[f]	0.3915	1.78E-04	split spoon	"
	83B	299-E25-234	25.3						sand (2)	Hanford sand	0.1157	1.4027	0.0070[f]	0.3696	1.78E-04	split spoon	"
	99A	299-E25-234	30.2	0	34	60	4	2	sand (2)	Hanford sand	0.7417	1.2557	0.0000	0.3692	2.24E-04	split spoon	"
	99B	299-E25-234	30.2						sand (2)	Hanford sand	0.3823	1.3262	0.0100	0.3765	2.24E-04	split spoon	"
	110A	299-E25-234	33.5	6	64	23	5	2	sand (2)	Hanford sand	0.1964	1.8193	0.0324	0.4293	2.82E-04	split spoon	"

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	$Theta_r$	$Theta_s$	K_s (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									
Grout[1,5] (cont.)	110B	299-E25-234	33.5						sand (2)	Hanford sand	0.1991	1.8015	0.0326	0.4201	2.82E-04	split spoon	"
	117A	299-E25-234	35.7	3	62	26	5	4	sand (2)	Hanford sand	0.1114	1.6538	0.0259	0.4538	3.63E-03	split spoon	"
	117B	299-E25-234	35.7						sand (2)	Hanford sand	0.0230	1.5237	0.0011	0.3831	3.63E-03	split spoon	"
	126A	299-E25-234	38.4	51	33	14	1	1	sandy gravel (5)	Hanford sand	0.9193	1.3700	0.0106	0.1755	1.98E-03	split spoon	"
	126B	299-E25-234	38.4						sandy gravel (5)	Hanford sand	0.4783	1.4639	0.0127	0.1823	1.98E-03	split spoon	"
	133A	299-E25-234	40.5	30	33	25	9	3	silty sandy gravel (3)	Hanford sand	0/0163	1.3134	0.0000	0.1877	2.76E-05	split spoon	"
	133B	299-E25-234	40.5						silty sandy gravel (3	Hanford sand	0.0331	1.2555	0.0000	0.1871	2.76E-05	split spoon	"
Injection[2,4]	1-1417	299-E24-95	1.8	1	23	68	7	1	sand (2)	Hanford sand	0.0051	1.6827	0.0200[f]	0.3501	1.40E-04	core barrel	relyea 1995
	1-1418	299-E24-95	3.0	18	56	26	0	0	sand (2)	Hanford sand	0.0310	1.5289	0.0336	0.2152	1.80E-04	core barrel	"
	1-1419	299-E24-95	4.9	2	88	10	0	0	sand (2)	Hanford sand	0.4984	1.4065	0.0090	0.3013	3.20E-04	core barrel	"
	2-1636	299-E24-95	4.9	2	84	14	0	0	sand (2)	Hanford sand	0.1385	1.7079	0.0228	0.3073	8.70E-04	core barrel	"
	2-1637	299-E24-79	9.8	0	80	20	0	0	sand (2)	Hanford sand	0.0760	1.8863	0.0248	0.3026	4.20E-03	core barrel	"
	2-1638	299-E24-79	12.2	0	81	19	0	0	sand (2)	Hanford sand	0.1016	1.3365	0.0000	0.2720	5.80E-03	core barrel	"
	2-1639	299-E24-79	18.3	0	93	7	0	0	sand (2)	Hanford sand	0.3333	1.5801	0.0179	0.3206	1.30E-03	core barrel	"
	2-2225	299-E24-92	9.8	0	80	20	0	0	sand (2)	Hanford sand	0.0242	4.1695	0.0335	0.3309	5.50E-03	core barrel	"
	2-2226	299-E24-92	15.2	6	90	4	0	0	sand (2)	Hanford sand	0.5282	1.4780	0.0168	0.2861	1.50E-02	core barrel	"
	2-2227	299-E24-92	18.3	2	92	6	0	0	sand (2)	Hanford sand	0.1216	1.7364	0.0154	0.3271	8.70E-03	core barrel	"
	2-2228	299-E24-95	15.2	1	97	2	0	0	sand (2)	Hanford sand	0.8612	1.4523	0.0092	0.2925	2.10E-02	core barrel	"
	2-2229	299-E24-95	18.3	1	94	5	0	0	sand (2)	Hanford sand	0.1358	1.8345	0.0197	0.3070	6.40E-03	core barrel	"
	2-2230	29-E24-79	1.8	2	32	52	11	3	sand (2)	Hanford sand	0.0066	2.1407	0.0608	0.3309	2.30E-04	core barrel	"
	2-2231	29-E24-79	3.0	12	52	36	0	0	gravelly sand (4)	Hanford sand	0.0063	1.7824	0.0685	0.2811	7.50E-03	core barrel	"
	2-2232	299-E24-79	4.9	4	88	8	0	0	sand (2)	Hanford sand	0.0452	2.0873	0.0279	0.2450	4.10E-02	core barrel	"

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	Theta$_r$	Theta$_s$	K$_s$ (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									
Injection[2,4] (cont)	2-2233	299-E24-79	7.9	2	90	8	0	0	sand (2)	Hanford sand	0.3460	1.4491	0.0130	0.2906	1.70E-02	core barrel	"
	2-2234	299-E24-79	11.0	0	86	14	0	0	sand (2)	Hanford sand	0.0664	1.5548	0.0123	0.2782	2.10E-02	core barrel	"
U.S. Ecology[1,3] MW-5	50	699-35-58	15.2	1	75	18	6	0	sand (2)	Hanford sand	0.0395	2.6308	0.0367	0.3309	3.53E-02	split spoon	Bergeron et al. 1987
	70	699-35-58	21.3	0	38	51	11	0	sand (2)	Hanford sand	0.0142	4.7700	0.0300[f]	0.4431	1.57E-03	split spoon	"
	90	699-35-58	27.4	0	81	15	4	0	sand (2)	Hanford sand	0.0454	3.0831	0.0250	0.3854	2.26E-03	split spoon	"
	130	699-35-58	39.6	0	28	68	4	0	sand (2)	Hanford sand	0.0150	4.9138	0.0250[f]	0.4163	4.42E-02	split spoon	"
	170	699-35-58	51.8	0	52	42	6	0	sand (2)	Hanford sand	0.0226	3.5335	0.0334	0.3927	3.81E-03	split spoon	"
	190	699-35-58	57.9	1	84	11	4	0	sand (2)	Hanford sand	0.0473	2.8261	0.0200[f]	0.4532	5.78E-03	split spoon	"
	210	699-35-58	64.0	3	85	8	4	0	sand (2)	Hanford sand	0.0751	2.2980	0.0321	0.2724	5.42E-03	split spoon	"
	230	699-35-58	70.1	0	77	18	5	0	sand (2)	Hanford sand	0.0393	3.1424	0.0100[f]	0.4193	5.31E-03	split spoon	"
	270	699-35-58	82.3	0	62	23	15	0	loamy sand (1)	Hanford sand	0.0244	1.5601	0.0200[f]	0.3270	5.54E-04	split spoon	"
	300	699-35-58	91.4	59	19	13	9	0	sandy gravel (5)	Middle Ringold	0.0105	1.6304	0.0123	0.1190	7.66E-04	split spoon	"
U.S. Ecology[1,3] MW-8	14.5	699-36-58B	4.4	0	78	18	4	0	sand (2)	Hanford sand	0.0425	3.1199	0.0395	0.4308	1.70E-03	split spoon	"
	145	699-36-58B	44.2	0	3	58	40	0	sandy loam (1)	Hanford sand	0.0110	2.8937	0.0200[f]	0.4233	8.86E-04	split spoon	"
	185	699-36-58B	56.4	22	68	7	3	0	gravelly sand (4)	Hanford sand	0.0735	2.0899	0.0288	0.3074	7.19E-03	split spoon	"
U.S. Ecology[1,3] MW-10	45	699-36-58A	13.7	1	69	20	10	0	sand (2)	Hanford sand	0.0288	2.2830	0.0385	0.3385	5.31E-03	split spoon	"
	86	699-36-58A	26.2	0	55	38	7	0	sand (2)	Hanford sand	0.0355	2.0852	0.0314	0.3822	1.97E-02	split spoon	"
	105	699-36-58A	32.0	1	62	24	13	0	loamy sand (1)	Hanford sand	0.0233	1.9835	0.0408	0.3267	1.73E-02	split spoon	"
	125	699-36-58A	38.1	1	59	30	10	0	sand (2)	Hanford sand	0.0210	2.8388	0.0429	0.3638	7.39E-03	split spoon	"
	165	699-36-58A	50.3	1	59	30	10	0	sand (2)	Hanford sand	0.0186	3.4294	0.0373	0.3233	6.63E-03	split spoon	"
	195	699-36-58A	59.4	24	57	13	6	0	gravelly sand (4)	Hanford sand	0.0312	2.0934	0.0298	0.2621	2.65E-03	split spoon	"
	205	699-36-58A	62.5	10	71	12	7	0	sand (2)	Hanford sand	0.0503	1.7946	0.0258	0.2969	6.65E-03	split spoon	"

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	$Theta_r$	$Theta_s$	K_s (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									
U.S. Ecology[1,3] MW-10	245	699-36-58A	74.7	0	71	20	9	0	sand (2)	Hanford sand	0.0319	2.3729	0.0321	0.3686	7.39E-03	split spoon	"
	265	699-36-58A	80.8	0	64	25	11	0	sand (2)	Hanford sand	0.0259	2.5903	0.0160[f]	0.3589	2.65E-03	split spoon	"
	285	699-36-58A	86.9	0	64	26	10	0	sand (2)	Hanford sand	0.0282	2.6922	0.0170[f]	0.3648	3.54E-03	split spoon	"
	300	699-36-58A	91.4	0	71	22	7	0	sand (2)	Hanford sand	0.0291	3.1582	0.0281	0.3668	4.42E-03	split spoon	"
U.S. Ecology[1,3] VOC[2,4]	3-0647[x]	299-W18-246	42.9	0	2	78	14	6	loamy sand (1)	Plio-Pleistocene	0.0051	2.0531	0.0400[f]	0.4995	2.00E--04	split spoon	Relyea 1995
	3-0648	299-W18-246	59.6	62	18	20	0	0	sandy gravel (5)	Middle Ringold	0.0124	1.6450	0.0000	0.1462	8.70E-03	split spoon	"
	3-0649	299-W18-247	41.1	0	10	38	40	12	loam (1)	Plio-Pleistocene	0.0010	1.7024	0.0600[f]	0.5331	N/A	split spoon	"
	3-0650	299-W18-247	45.1	0	46	28	15	11	sandy loam (1)	Plio-Pleistocene	0.0120	1.5539	0.2412	0.6306	2.60E-07	split spoon	"
	3-0651	299-W18-247	46.9	0	58	24	9	9	loamy sand (1)	Plio-Pleistocene	0.0286	1.9721	0.1006	0.3728	9.40E-03	split spoon	"
	3-0652	299-W18-248	38.4	0	40	52	4	4	sand (2)	Hanford Sand	0.0092	1.8848	0.0300[f]	0.3586	3.70E-04	split spoon	"
	3-0653	299-W18-248	42.5	0	24	54	14	8	loamy sand (1)	Plio-Pleistocene	0.0067	1.8378	0.1096	0.4223	5.80E-06	split spoon	"
	3-0654	299-W15-216	35.6	59	30	3	4	4	sandy gravel (5)	Plio-Pleistocene	0.0119	1.2618	0.0186	0.1933	2.70E-04	split spoon	"
	3-0655	299-W15-216	36.9	34	28	8	24	6	silty sandy gravel (3)	Upper Ringold	0.0029	1.6285	0.0559	0.2625	1.58E-04	split spoon	"
	3-0656	299-W15-216	39.0	42	40	18	0	0	sandy gravel (5)	Middle Ringold	0.0166	1.3941	0.0090	0.1814	1.36E-02	split spoon	"
	3-0657	299-W15-217	37.4	34	38	10	10	8	silty sandy gravel (3)	Hanford sand	0.0145	1.3692	0.0469	0.2505	2.67E-04	split spoon	"
U.S. Ecology[1,3] W-049-H[2,4]	2-2865[x]	699-42-37	38.7	0	22	58	14	6	loamy sand (3)	Lower Ringold	0.0038	2.0069	0.1612	0.5868	2.30E-06	split spoon	Delaney 1992
	2-3084	699-41-39	24.7	82	14	4	0	0	sandy gravel (6)	Upper Ringold	0.0097	1.5700	0.0125	0.0579	1.30E-01	split spoon	"
		699-41-35	31.5	0	55	25	10	10	sandy loam (1)	Lower Ringold	0.0142	1.2598	0.2705	0.6772	1.40E-08	split spoon	"
		699-42-37	4.6	65	20	12	3	0	sandy gravel (6)	Hanford gravels	0.0038	1.5977	0.0197	0.1071	1.30E-03	split spoon	"
		699-42-37	28.3	0	35	30	27	8	sandy loam (1)	Hanford sand	0.0035	1.3657	0.1808	0.5336	3.20E-07	split spoon	"
		699-40-36	29.3	68	19	6	7	0	sandy gravel (5)	Hanford gravels	0.0095	1.5556	0.0156	0.1128	1.82E-04	split spoon	"
		699-40-36	65.8	65	21	14	0	0	sandy gravel (5)	Basal Ringold	0.0054	1.4011	0.0538	0.1953	6.30E-07	split spoon	"

Table C-2. Summary of Soil Physical and Hydraulic Parameters in the 200 Areas.

Site	Sample No.	Borehole	Depth (m.)	Sieve Analysis					Soil Type #	Formation	Alpha (L/cm)	n	$Theta_r$	$Theta_s$	K_s (cm/s)	Sampling Technique	Source
				gr	cs	fs	silt	clay									

[a] soil category:
(1) - SS, sand mixed with finer fraction
(2) - S, sand
(3) - SSG, sand and gravel mixed with finer fraction
(4) - GS, gravelly sand
(5) - SG1, sandy gravel with gravel content approximately <60 percent
(6) - SG2, sandy gravel with gravel content approximately >60 percent

[f] signifies that the residual moisture content has been fixed to improve the curve fit through the measured data.
[x] sample contains swelling clay.
[1] Kn measured by falling-head permeameter.
[2] Kn measured by constant-head permeameter.

Moisture-Retention Data Measurement
[3] 0 cm to -60 cm, hanging water column; -100 cm to -15300 cm, pressure plate extraction (Klute 1986).
[4] 0 cm to-1000 cm, Tempe cell; -500 to -15300 cm, pressure plate extraction.
[5] 0 cm to -150 cm, hanging water column; -350 cm to -15300 cm, pressure plate extraction; 15300 cm, thermocouple psychrometer (Rawlins and Campbell 1986).
[6] 0 cm to -1000 cm, Tempe cell; -500 cm to -10000 cm, pressure plate extraction; <10000 cm, thermocouple psychrometer.

APPENDIX D

SORPTION DATA ON VADOSE ZONE SOILS UNDERLYING THE BY CRIBS

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APPENDIX D

SORPTION DATA ON VADOSE ZONE SOILS UNDERLYING THE BY CRIBS

Appendix D summarizes the sorption experiments conducted on vadose zone soils underlying the BY cribs. These experiments were completed to support the remedial investigation of the 200-BP-1 Operational Unit. Because these soils adjoin vadose zone beneath the B-BX-BY waste management area, they are considered representative of these soils. The sorption results on these soils, therefore, should indicate the geochemical mobility of contaminants tested within the B-BX-BY waste management area vadose zone.

Letter Report for Westinghouse Hanford Company

ADSORPTION OF Co-60, Sr-90, Tc-99, Cs-137, Pu and CYANIDE On 200-BP-1 SEDIMENT

K. J. Cantrell
R. J. Serne

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

The purpose of this study was to acquire adsorption data useful for modeling the transport of Co-60, Sr-90, Tc-99, Cs-137, Pu and cyanide in groundwater in the vicinity of the 200-BP-1 operable unit cribs. Batch adsorption experiments were conducted to determine distribution or adsorption coefficients (R_d) between representative 200-BP-1 sediments and Hanford groundwater. R_d is defined as the ratio of the concentration of the constituent of interest in the solid phase over that in the liquid phase. The R_d values were determined for two different sediments samples (699-52-57 and 699-55-55). The groundwater used in these experiments was collected from well 699-50-53, which is located in the proximity of the 200-BP-1 cribs. Results of our studies are summarized in Table 1. The values in Table 1 are the average of three individual experiments.

Table 1. Average R_d (mL/g)values determined between 200-BP-1 sediment and groundwater.

Sediment	Constituent	R_d
699-52-57	Co-60	0.2
699-52-57	Sr-85	8.5
699-52-57	Tc-95m	0.0
699-52-57	Cs-137	2000
699-52-57	Pu-238	> 340
699-52-57	Cyanide (150 ppb)	< 0.7
699-52-57	Cyanide (2000 ppb)	< 0.2
699-55-55	Co-60	0.1
699-55-55	Sr-85	6.4
699-55-55	Tc-95m	0.05
699-55-55	Cs-137	2400
699-55-55	Pu-238	> 615
699-55-55	Cyanide (150 ppb)	< 1.5
699-55-55	Cyanide (2000 ppb)	< 0.5

METHODS

In general, the batch adsorption experiments were conducted in accordance with methodologies described in Relyea, Serne and Rai (1980). Specifically, 30 mls of groundwater solution spiked with the radionuclide of interest was added to a polycarbonate or glass centrifuge tube along with approximately 1 gram of sediment. Ten grams of sediment were used in the case of the cyanide experiments. Co-60, Sr-85, Tc-95m, Cs-137, Pu-238 and C-14 labeled cyanide were used as tracers in these

experiments. In all cases, except for cyanide, the radionuclides were added at trace concentrations. In the cyanide experiments carrier potassium cyanide was added to increase the concentration of cyanide to 150 and 2000 ppb. Prior to the addition of the spiked solution, the soil was pre-equilibrated three times with unspiked groundwater solution. After the spiked solution was added, the experiment was equilibrated for 14 days. Three replicates were conducted for each experiment. Two blanks (no sediment) were included with each experiment as well. In the case of the gamma emitters (Co-60, Sr-85, Tc-95m and Cs-137), the R_d was determined by direct measurement of the radionuclides both in solution and on the soil. In the case of alpha emitters (Pu-238) and beta emitters (C-14 labeled cyanide), shielding by the soil prevents direct determination of the soil concentrations. Because significant loss of Pu-238 was observed in the blanks, a mass balance approach assuming insignificant losses would have resulted in erroneous R_d determinations. Therefore, it was necessary to determine the soil concentrations of Pu-238. To determine the Pu-238 concentration in the soil, the soil was extracted with 1% HNO_3 solution.

The groundwater used in the bulk of the experiments was collected from well 699-50-53, which is near the 200-BP-1 operable unit cribs. Water from this well contains various contaminants including radionuclides, cyanide and nitrate. For comparison, some experiments were conducted with groundwater from well 6-S3-25. This well is uncontaminated. Prior to use in our experiments, the groundwater from well 699-50-53 was analyzed using gamma and scintillation counting to make sure that no radionuclides existed at concentrations high enough to interfere with the analysis of the added tracer radionuclides. Adsorption experiments were conducted on two different sediments samples. These sediment samples were collected and provided to us by WHC. The sediment samples were collected from the aquifer near the operable unit cribs at depths of 159.6' (sample id 699-52-57) and 210.0' (sample id 699-55-55).

RESULTS AND DISCUSSION

Results of the individual R_d determinations are compiled in Table 2. The averages of these values are shown in Table 1. The results for Sr-85, Tc-95m and Cs-137 are typical of results determined with other Hanford sediments[1] (Serne et al., 1990 and Serne et al., 1991), with Cs being strongly adsorbed, Tc not adsorbing and Sr adsorbing at an intermediate level. The negative values observed for Tc-95m are an artifact of experimental error being incorporated into the R_d calculation. Any negative value should be taken to be essentially zero.

The results determined for Pu-238 are also consistent with previous investigations of Pu adsorption on Hanford soil (Rhodes, 1957). The results determined in this study should be considered as lower bound estimates. This is because the acid extraction may not have completely removed all of the plutonium adsorbed onto the soil. This would cause the value determined for R_d to be underestimated. From a performance assessment perspective it is better to use a conservatively low value, rather than a value which is overestimated, because use of a conservatively low R_d will overestimate the migration potential.

Adsorption of Co-60 onto Hanford sediments is typically quite high (Serne et al., 1990 and Serne et al., 1991); however, the results shown in Tables 1 and 2 are very low. Three additional experiments were conducted to determine if the reduced cobalt adsorption was the result of constituents dissolved in the 699-50-53 water. In these

experiments, groundwater from well 6-S3-25 was used instead of the 699-50-53 along with 699-55-55 sediment. The average R_d value for these three experiments was 2560 mL/g. Apparently their is something in the 699-50-53 water which is not in the 6-S3-25 water that is preventing cobalt from adsorbing to the sediment.

Table 2. R_d (mL/g) values determined between 200-BP-1 sediment and groundwater.

Sediment	Constituent	R_d(1)	R_d(2)	R_d(3)
699-52-57	Co-60	0.05	0.27	0.23
699-52-57	Sr-85	8.69	8.66	8.03
699-52-57	Tc-95m	-0.03	-0.12	-0.03
699-52-57	Cs-137	1971	2077	1954
699-52-57	Pu-238	247	320	453
699-52-57	Cyanide (150ppb)	0.7	0.7	0.8
699-52-57	Cyanide (2000ppb)	0.2	0.1	-
699-55-55	Co-60	0.07	0.15	0.13
699-55-55	Sr-85	5.88	6.62	6.77
699-55-55	Tc-95m	0.10	0.01	0.01
699-55-55	Cs-137	2421	1907	2753
699-55-55	Pu-238	490	681	675
699-55-55	Cyanide (150ppb)	1.4	2.2	1.0
699-55-55	Cyanide (2000ppb)	0.2	1.1	0.2

Two plausible hypotheses could explain the cobalt results. The first hypothesis is that complexation of Co-60 with cyanide is preventing adsorption. A speciation calculation was conducted to estimate the extent of complexation with cyanide using the MINTEQA2 geochemical equilibrium code (Allison et al., 1991). Input data used for this calculation was taken from chemical data available for well 699-50-53. Cyanide concentrations measured in water from well 699-50-53 from 3/87 to 2/92 ranged from 110 ppb to 1690 ppb with an average of 809 ppb. Field pH values ranged from 7.5 to 8.3 and averaged to 8.0. Because stability constants for cobalt complexation with cyanide are not available, estimates were used. Based upon stability constant data for transition metals with other ligands containing nitrogen bonding groups, it was estimated that stability constants for cobalt complexation with cyanide would be most comparable to those of zinc. Using a total cyanide concentration of 809 ppb, a pH of 8.0 and the cyanide stability constants for zinc, the MINTEQA2 calculation results indicate that only 24% of the total cobalt would be complexed with cyanide. Although these results must be considered to be quite uncertain, they do suggest that complexation with cyanide is not strong enough to account for the very low cobalt adsorption from the 699-50-53 well water. Analyses were conducted to determine the actual cyanide concentration in the 699-50-53 well water used in the adsorption experiments. This analysis was performed by

PNL Analytical Services (325 and 329 Buildings). The results indicate the cyanide concentration was less than 2 ppb. This result is not consistent with previous analyses conducted on 699-50-53 well water. It is possible that cyanide was lost from the well water we collected because no preservatives were added to the water which could have prevented outgassing of hydrogen cyanide.

Another possible explanation for the low cobalt adsorption is complexation with EDTA. Stability constants for cobalt complexation with $EDTA^{4-}$ and $HEDTA^{3-}$ are quite high (Lindsay, 1979). It is known that equipment decontamination wastes from the 200 West Area and laboratory wastes from the 300 Area were routed through SSTs (single shell tanks) and then discharged to the ground on the 200 Area plateau (Waite, 1991). It is possible that these wastes contained EDTA; however, we are not aware of any documentation which could prove this. In addition, we are not aware of any analyses which have been done to determine if EDTA actually exists in 699-50-53 groundwater.

To determine if complexation with cyanide or EDTA could cause the reduced Co-60 adsorption which was observed, another suite of experiments was conducted. In this set of experiments Co-60 adsorption was determined on 699-52-57 soil with 6-S3-25 well water containing various concentrations of cyanide and EDTA. Results of these experiments are shown in Table 3.

Table 3. Co-60 R_d (mL/g) values determined between 200-BP-1 sediment (699-52-57) and 6-S3-25 groundwater at various concentrations of cyanide or EDTA.

Constituent	R_d(1)	R_d(2)	R_d(3)	Average
150 ppb CN	2.1	2.0	1.7	1.9
2000 ppb CN	0.0	0.1	0.0	0.0
25 ppb EDTA	1000	1230	982	1070
200 ppb EDTA	79	71	65	71
2000 ppb EDTA	2.6	3.4	3.8	3.3

Results shown in Table 3 indicate that cyanide concentrations which are typical for those measured in well 699-50-53 could result in greatly reduced Co-60 adsorption. In addition, high concentrations of EDTA could also account for reduced Co-60 adsorption on 200-BP-1 sediment. Such high concentrations of EDTA do not seem likely; however, as indicated earlier, no EDTA analyses of 699-50-53 well water are available at this time.

Cyanide R_d results illustrated in Tables 1 and 2 are expressed as an upper limit. This is because significant unaccountable loss of cyanide occurred during the experiments. For example, from 6 to 8.5 % of the initial cyanide in the blanks was lost during the experiment and could not be accounted for. The upper bound R_d values determined for cyanide and shown in Tables 1 and 2 were determined by assuming that all the cyanide lost from solution was adsorbed to the sediment. Results from the blank

experiments indicate that this is unlikely. As a result, the R_d values calculated in this manner are likely to be overestimates. The fact that the CN R_d value decreases as the concentration of CN increases suggests that if there is any true adsorption that the CN adsorption capacity of the soil is quite low. The lower bound for R_d is 0.0, which is the result for no adsorption. Although the values determined in this study must be considered as upper bound values they are consistent with values determined by other investigators. For example, Alesii and Fuller (1976) determined R_d values which ranged from 0.1 to 1.0 mL/g depending upon the type of soil and the form of cyanide.

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APPENDIX E

SUPPORTING GAMMA LOGGING DATA

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APPENDIX E

SUPPORTING GAMMA LOGGING DATA

Appendix E contains the drywell spectral gamma logging profiles that MACTEC-ERS prepared for the B, BX, and BY tank farms. The appendix also includes summaries using historically gross gamma and spectral gamma logs to deduce migration of gamma-emitting radionuclides in the vadose zone as a function of drywell location and time. These are for the BX and BY tank farms only. A similar summary is being completed for the B tank farm, but is not yet available.

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B TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-1. Plan View of Tanks and Boreholes in the B Tank Farm.

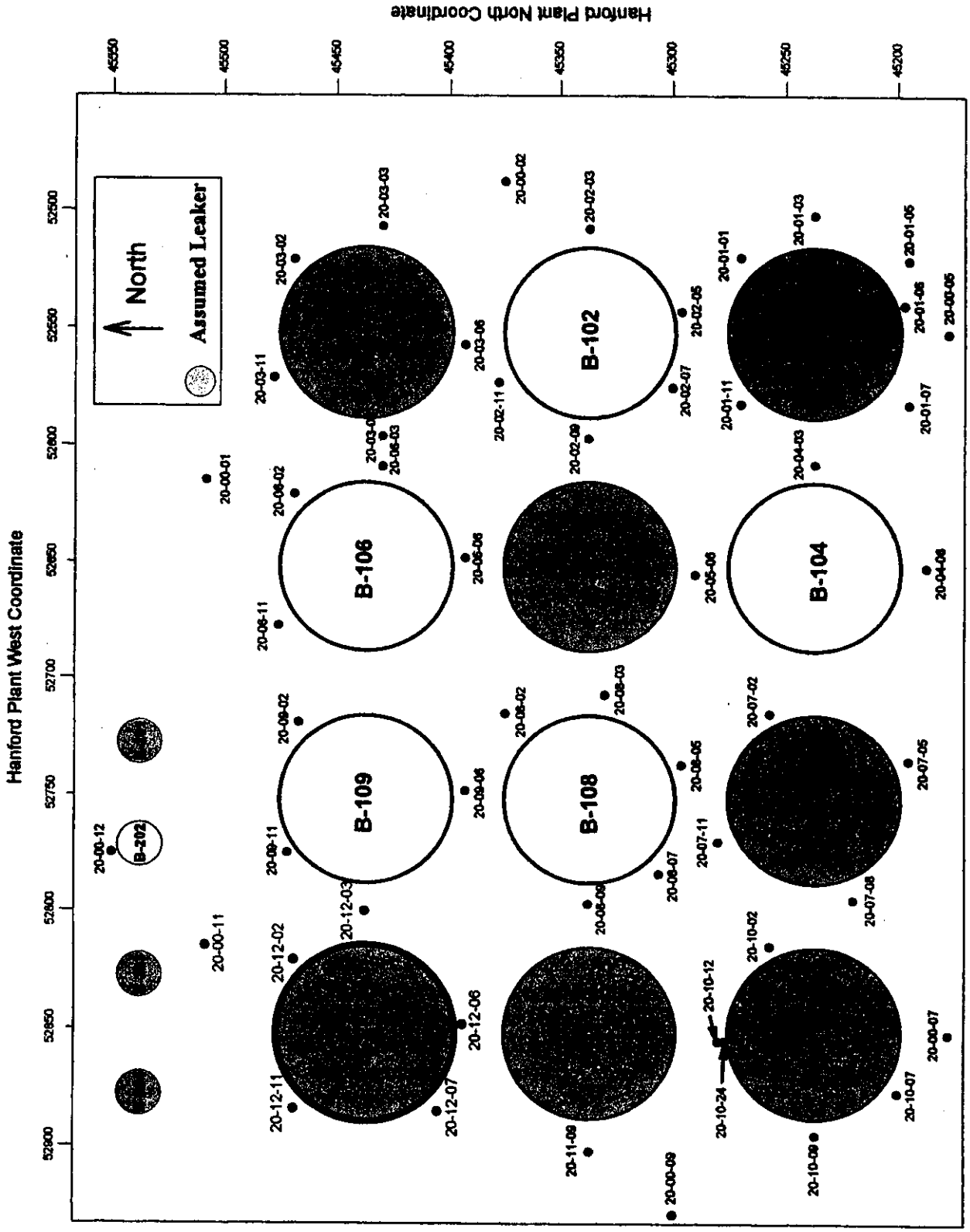


Figure E-2. Correlation Plot of the Synthetic Radionuclide Concentrations in Boreholes Surrounding Tank B-101. (sheet 1)

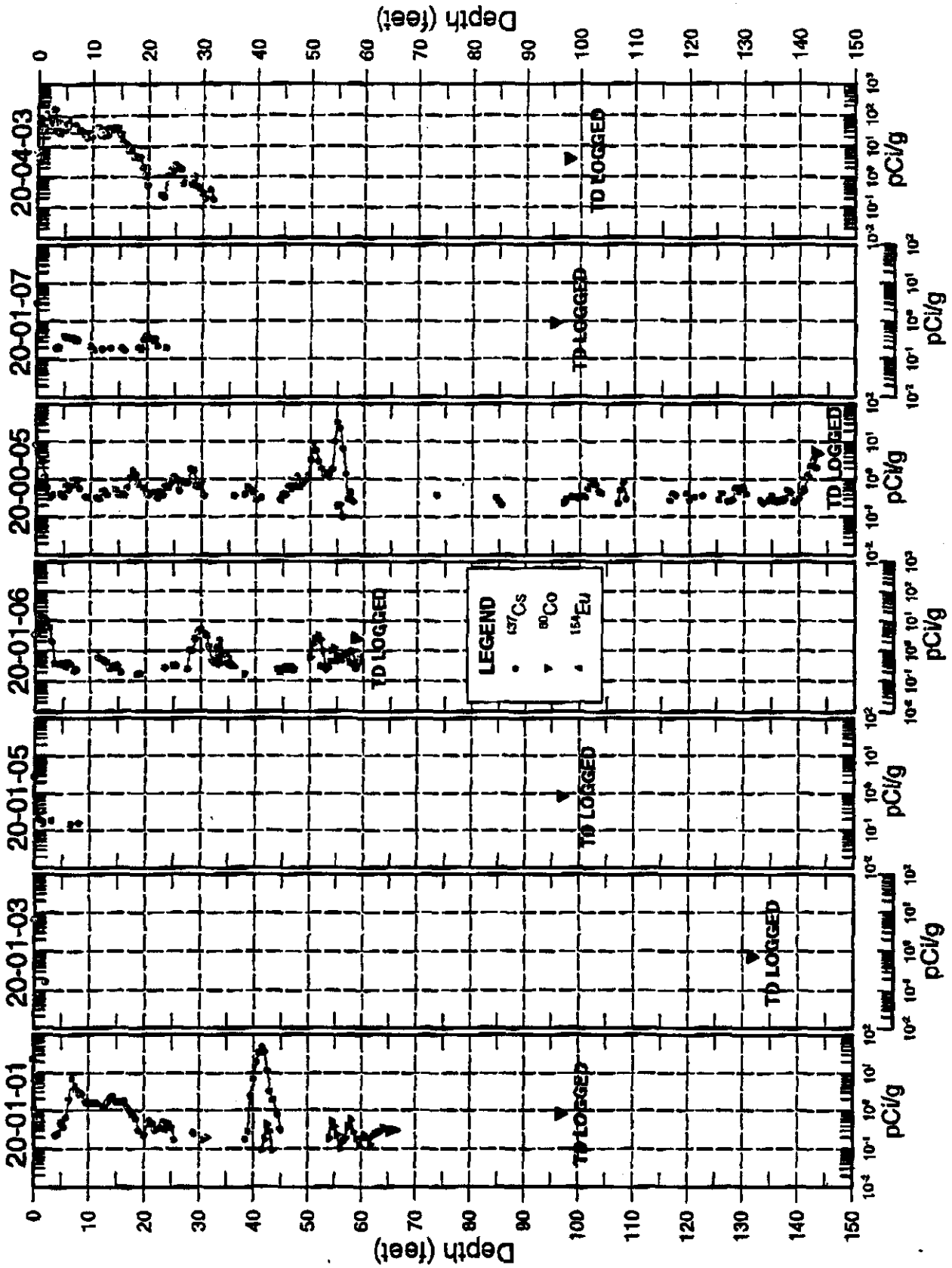


Figure E-2. Correlation Plot of the Synthetic Radionuclide Concentrations in Boreholes Surrounding Tank B-101. (sheet 2)

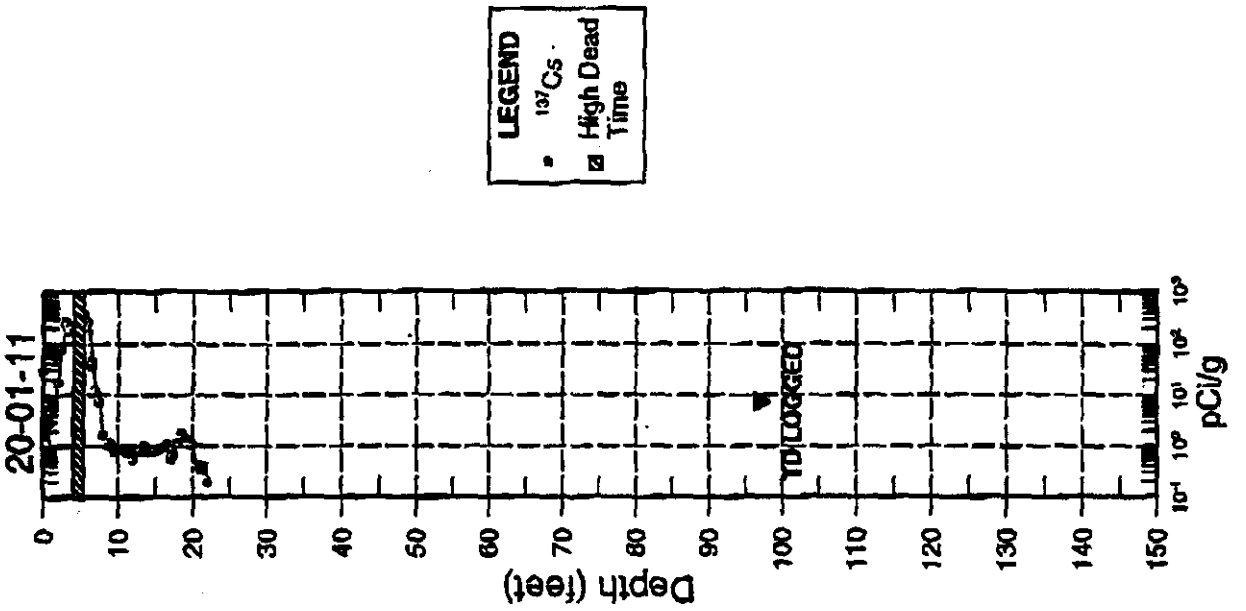


Figure E-3. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-102.

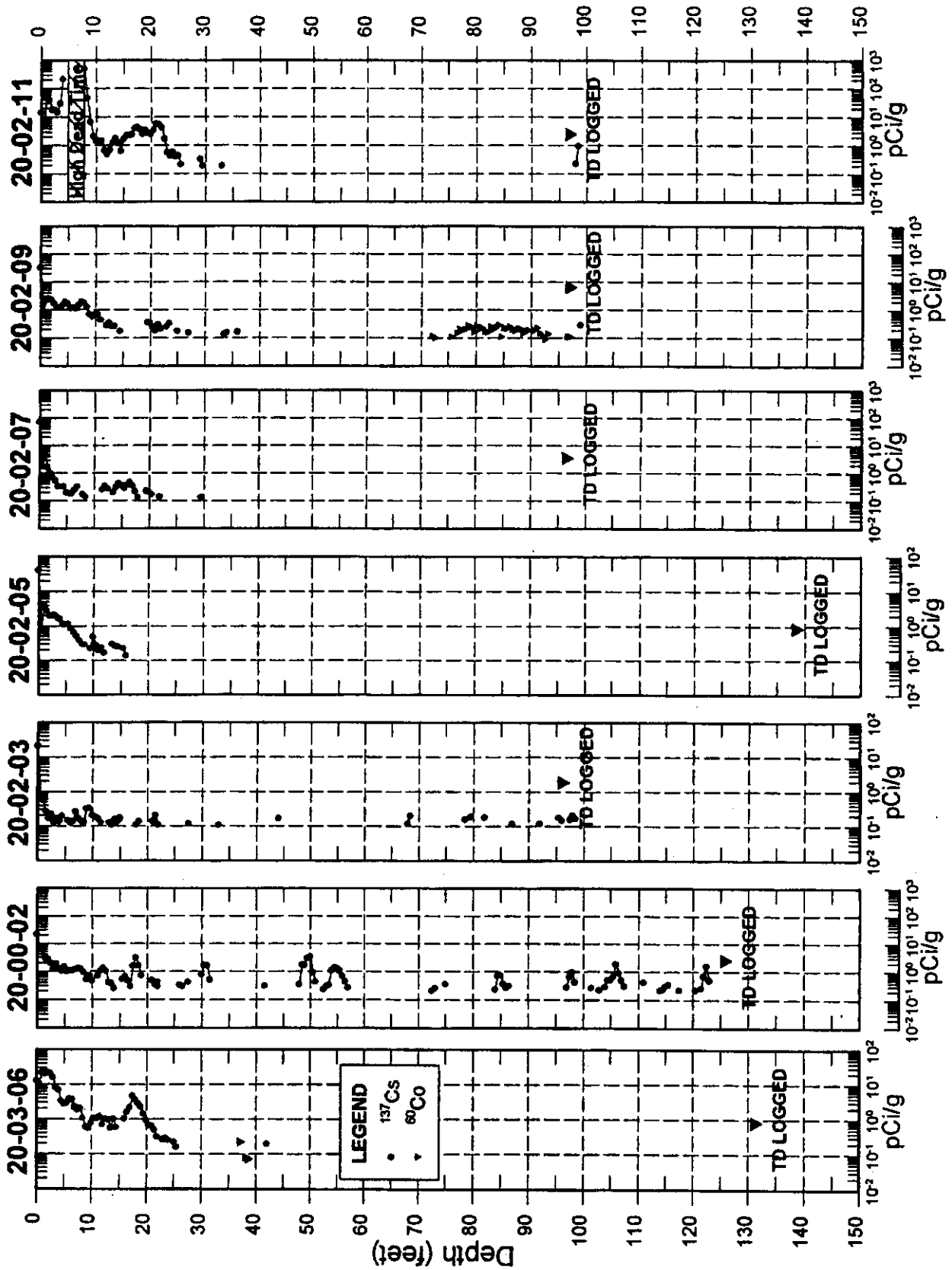


Figure E-4. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-104.

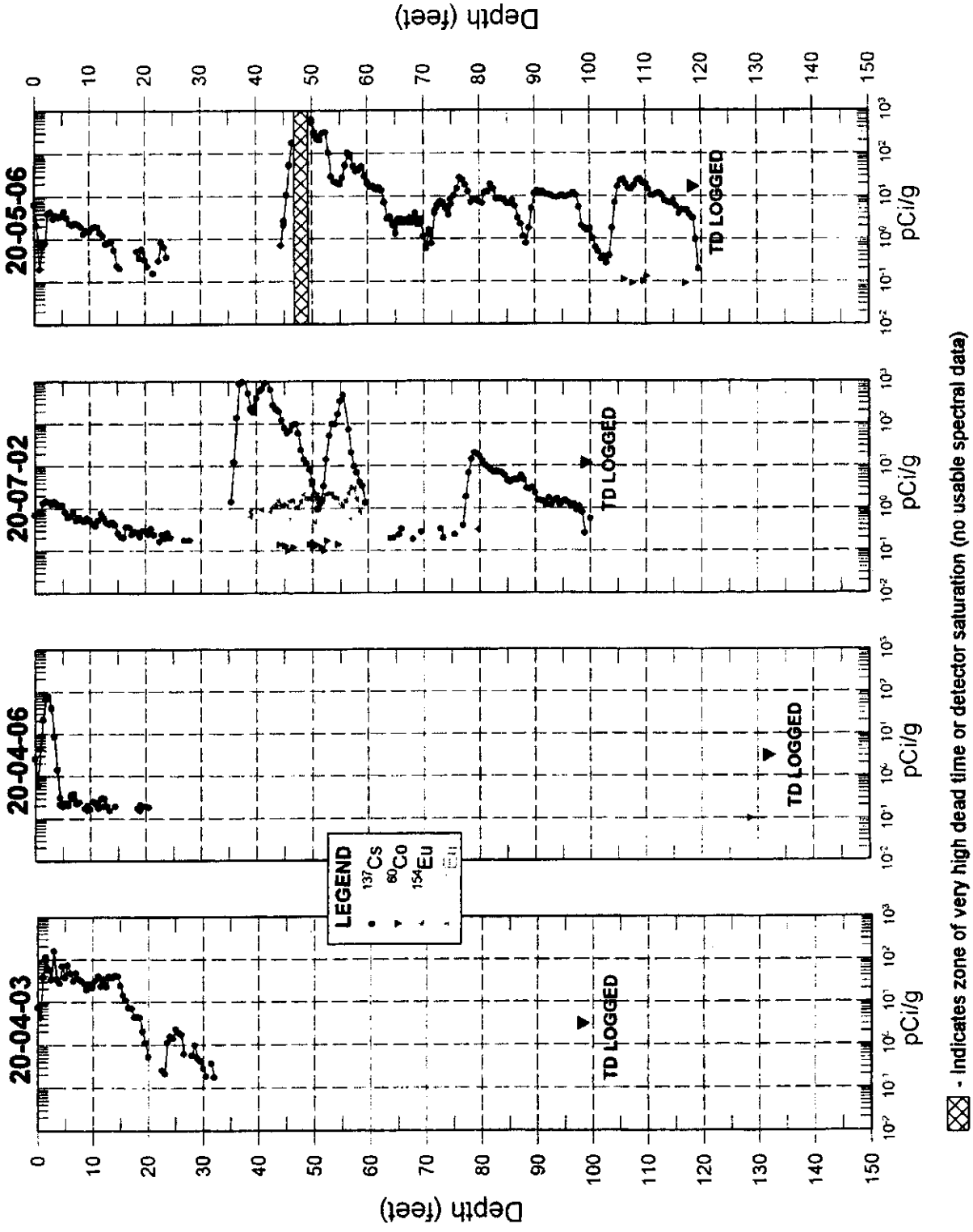


Figure E-5. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-105.

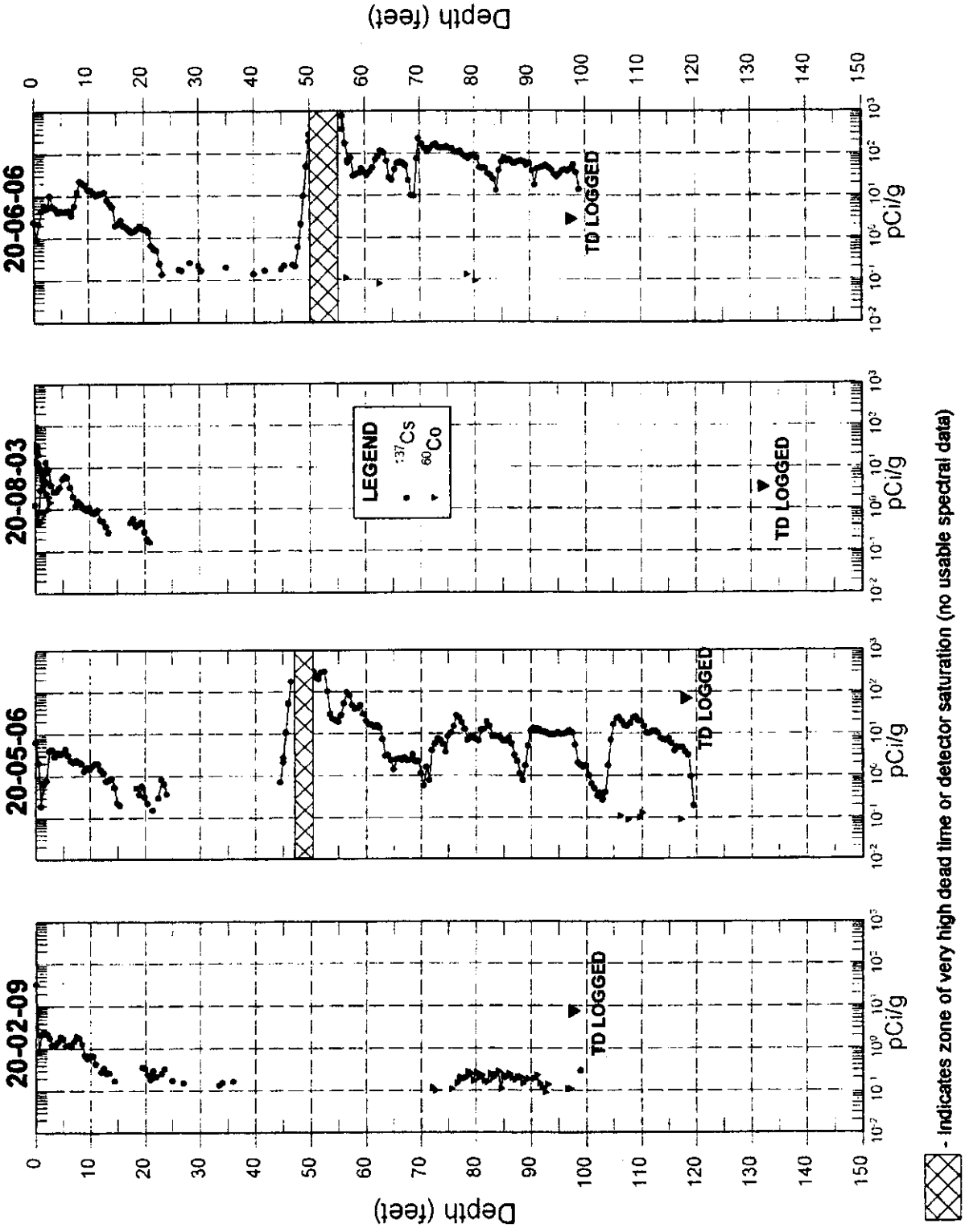


Figure E-6. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-106.

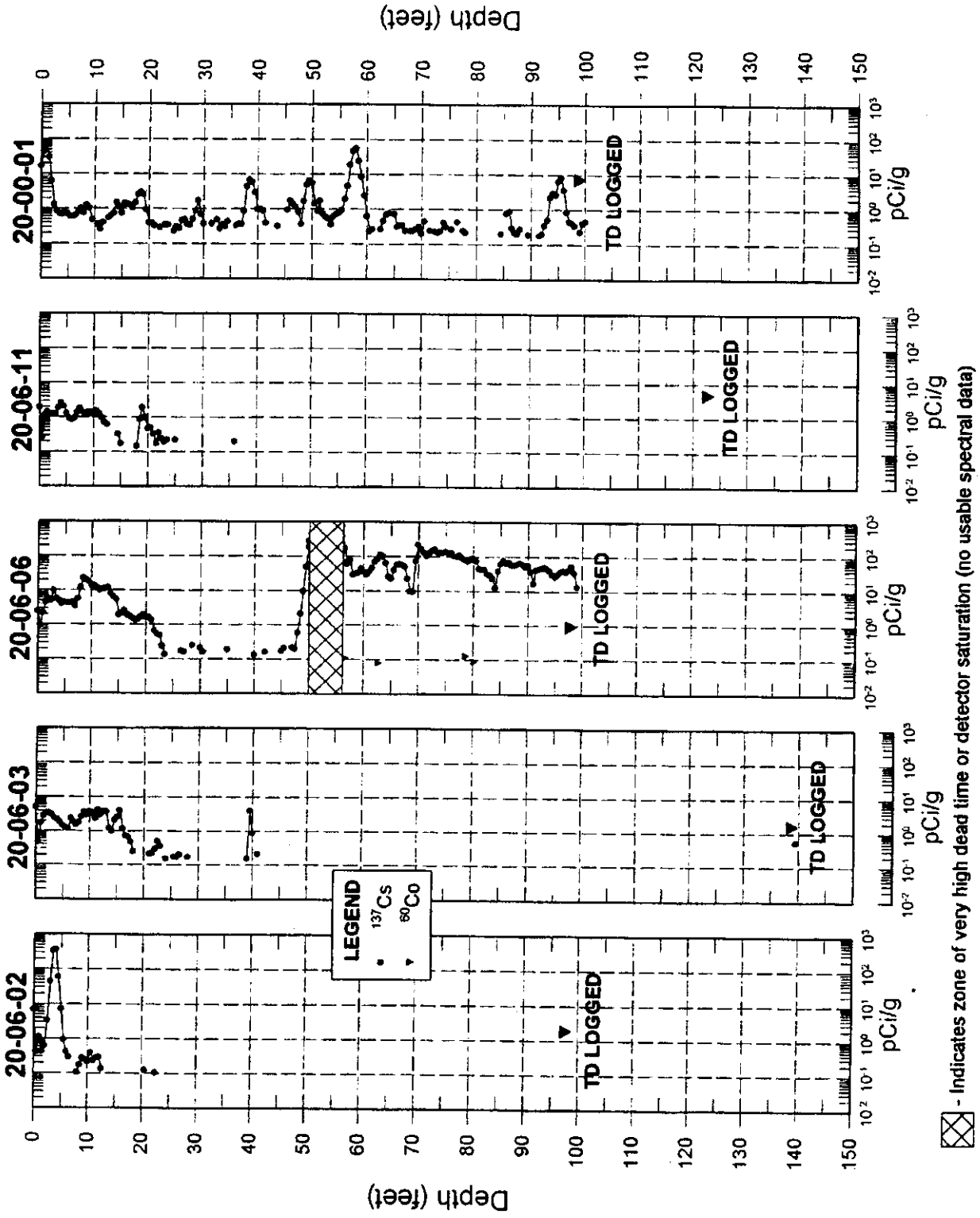


Figure E-7. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-107.

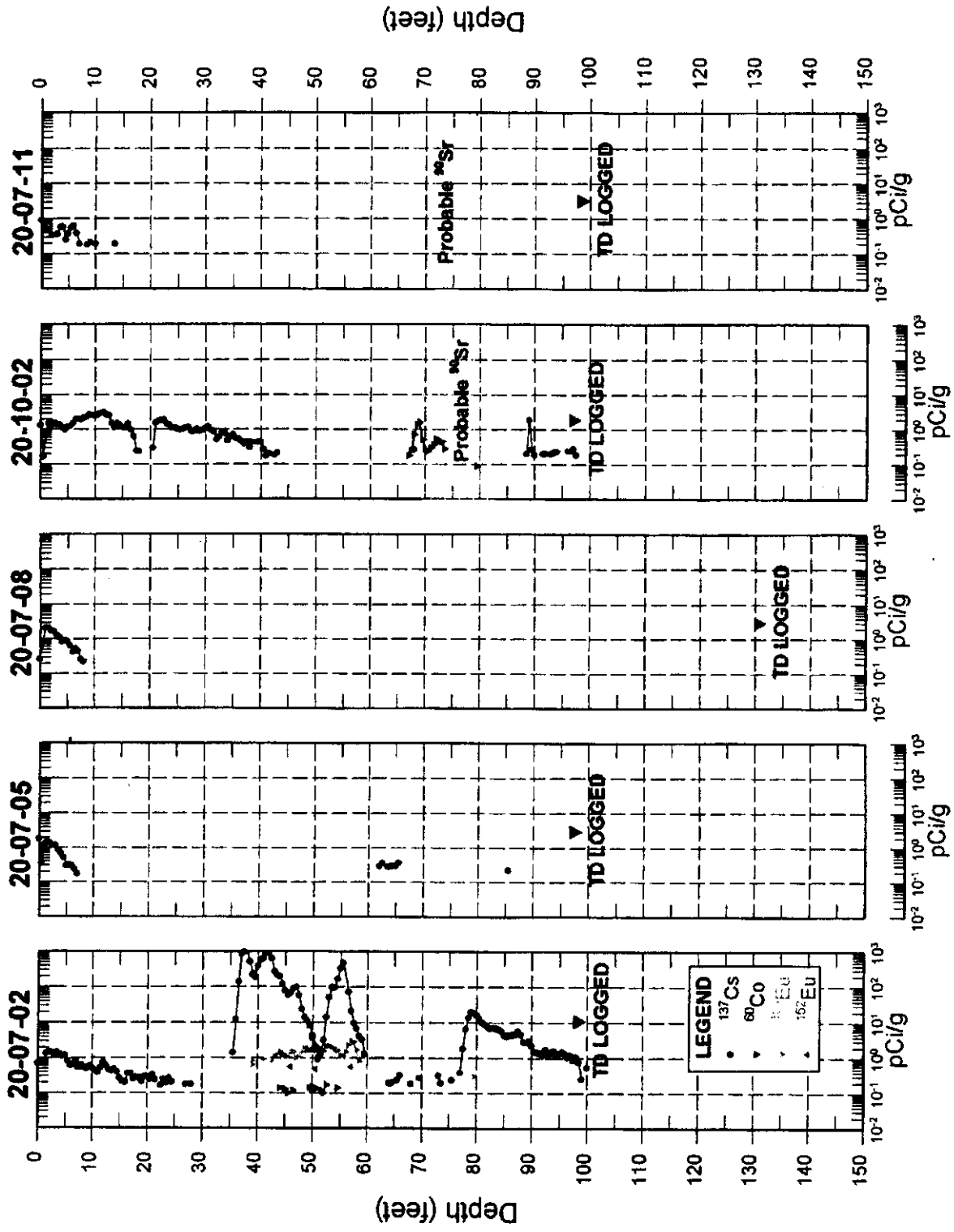


Figure E-8. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-108.

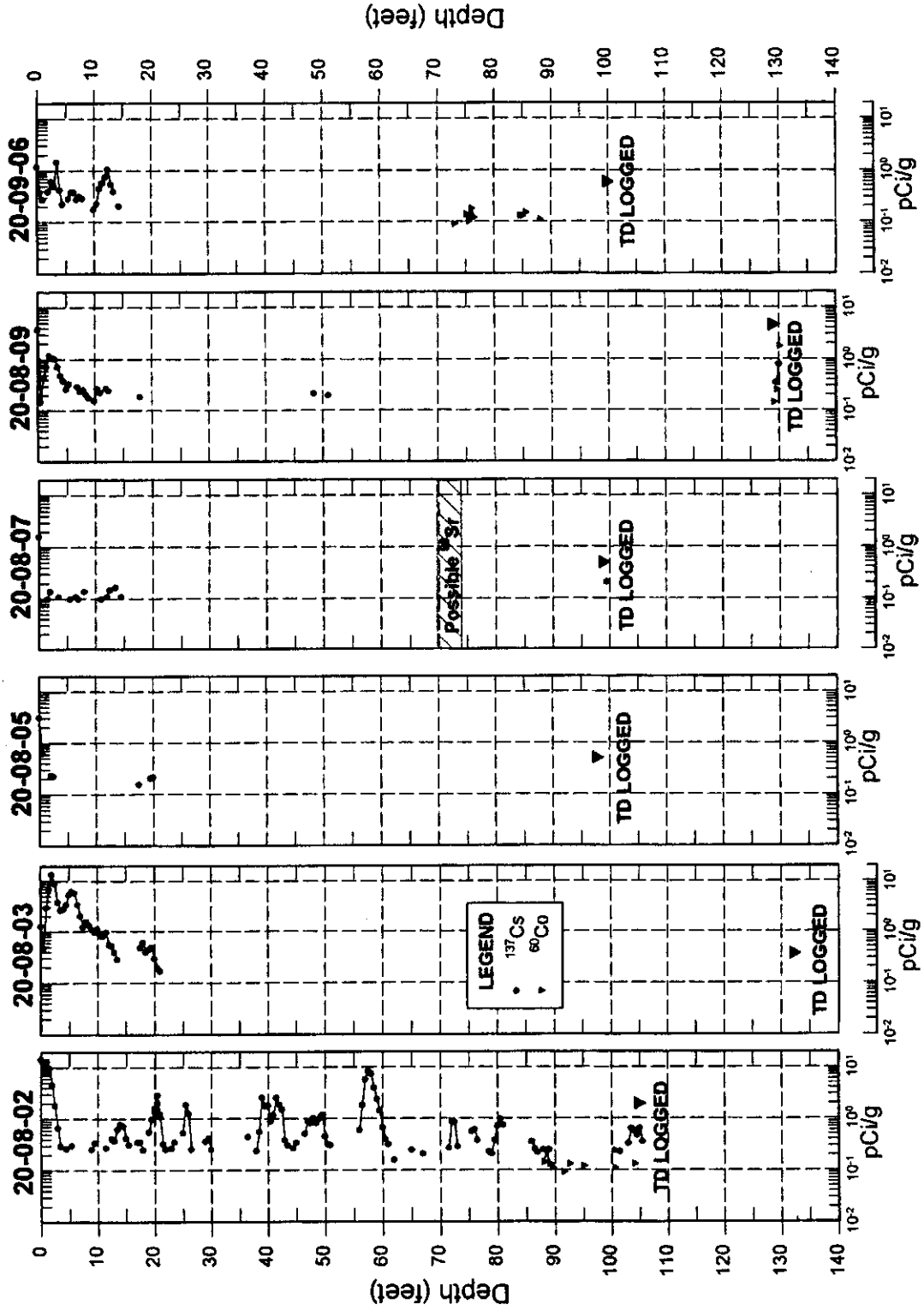


Figure E-9. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-109.

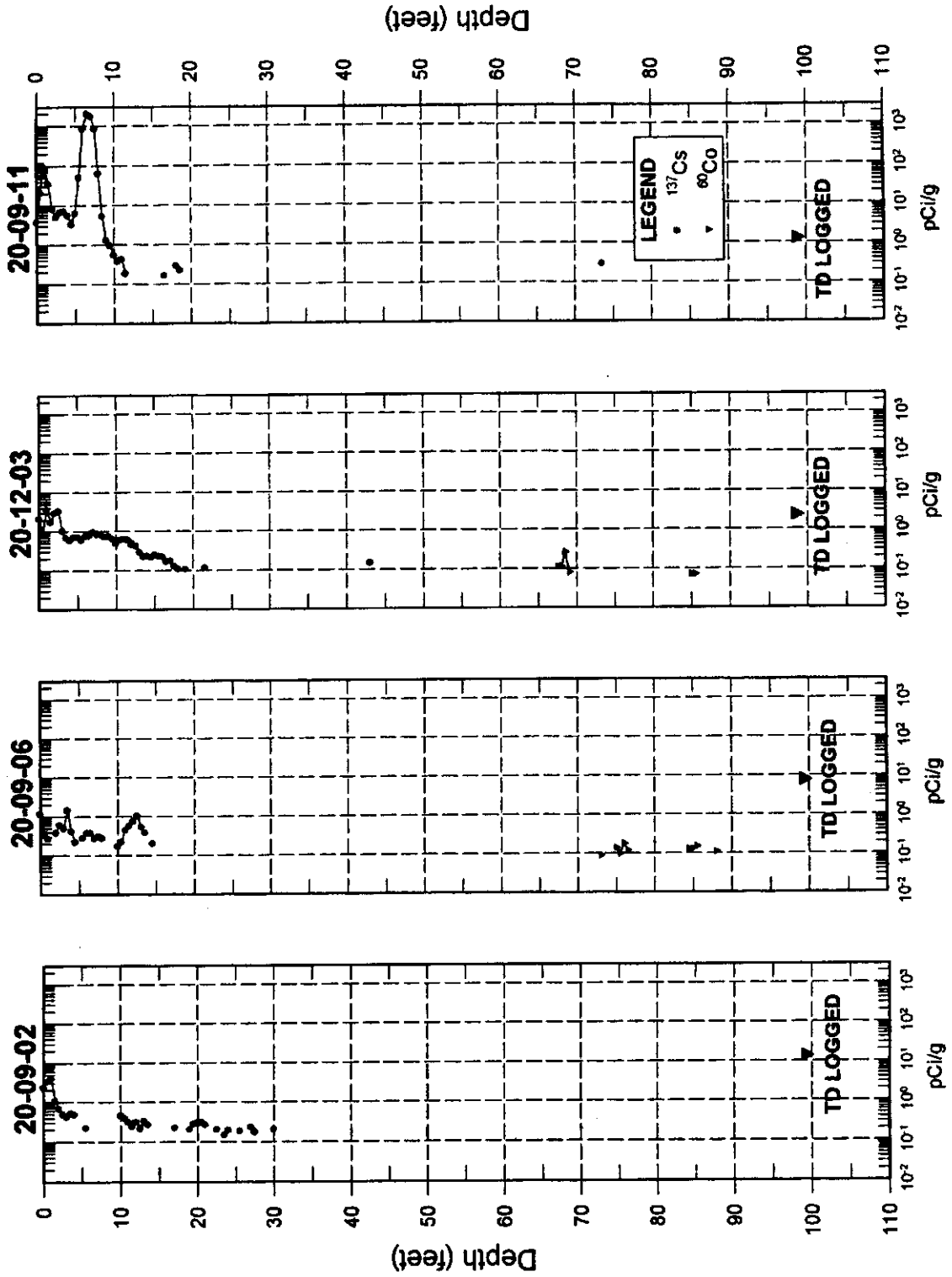


Figure E-10. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-110.

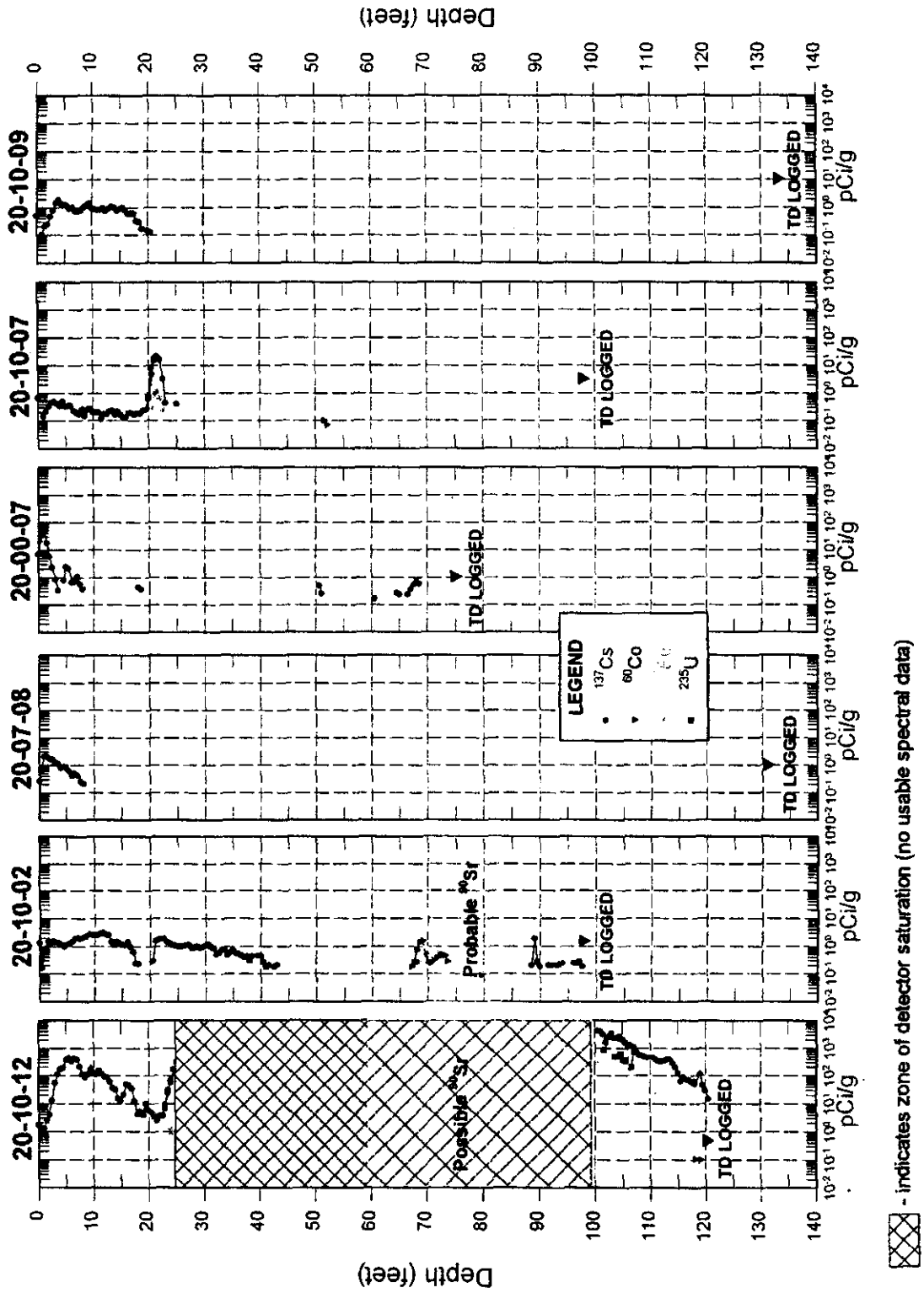


Figure E-11. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-111.

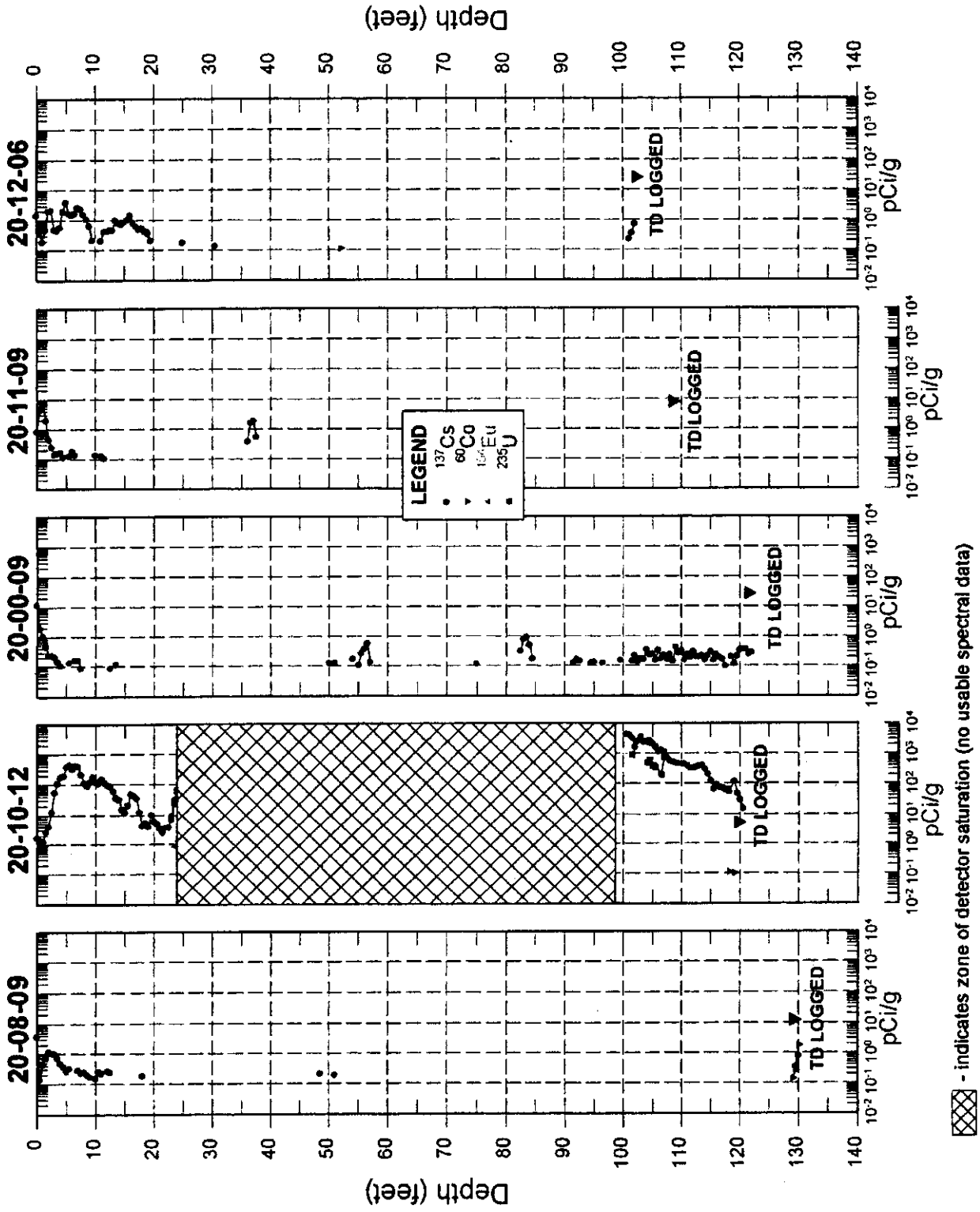
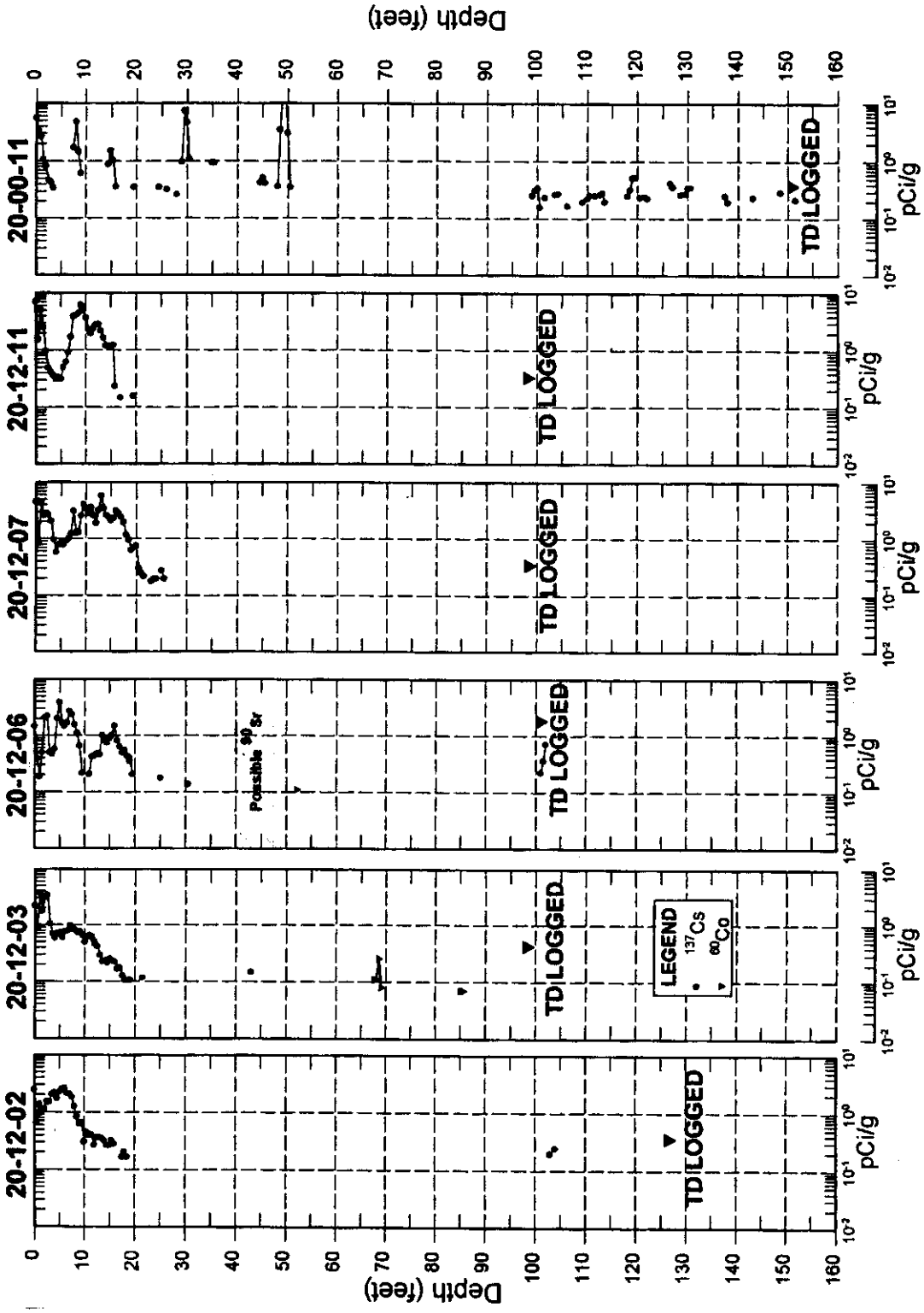


Figure E-12. Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-112.



BX TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-13. Plan Map of the BX Tank Farm Showing the Locations of the Tank Monitoring Boreholes.

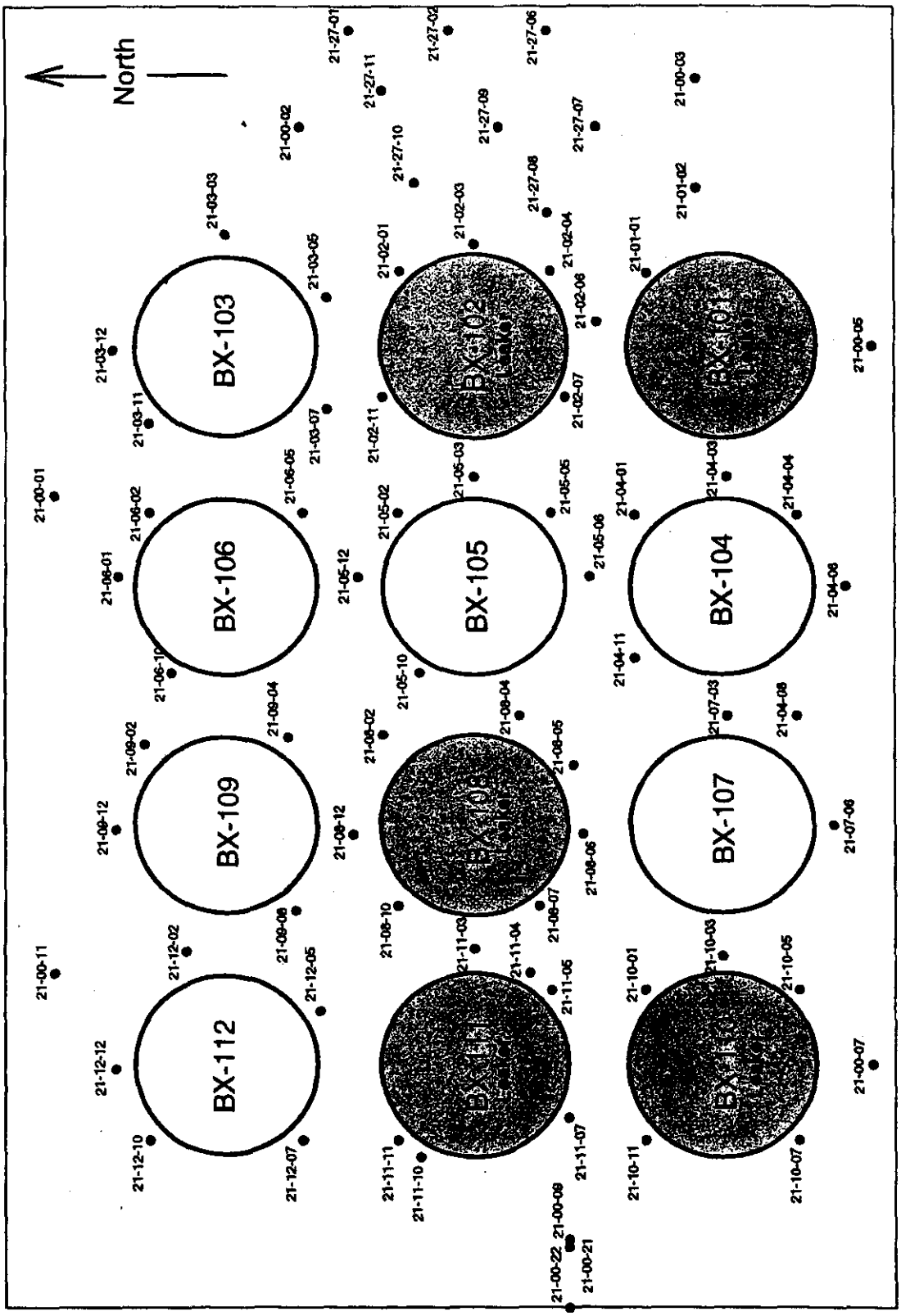


Figure E-14. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-101.

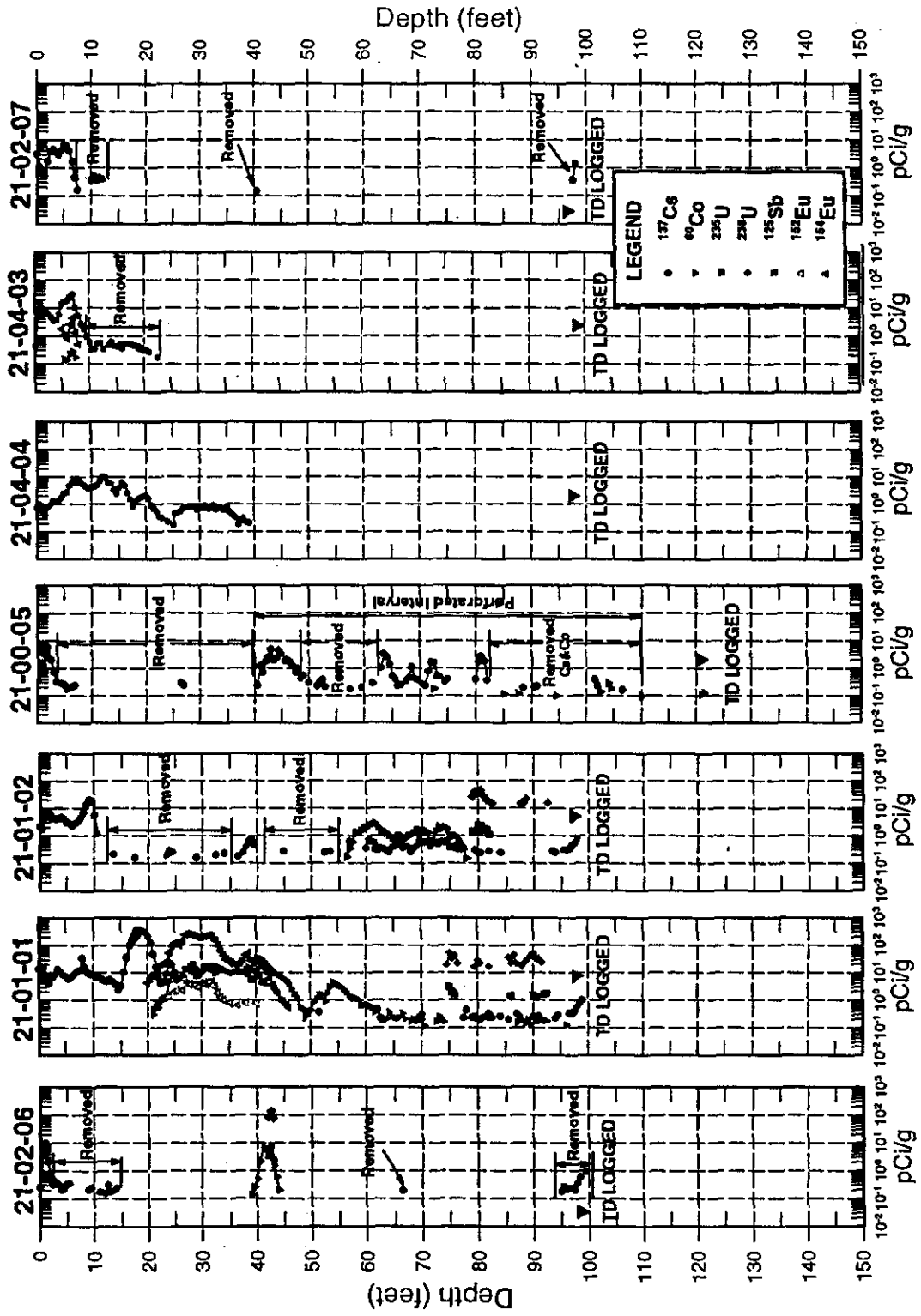


Figure E-15. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-102.

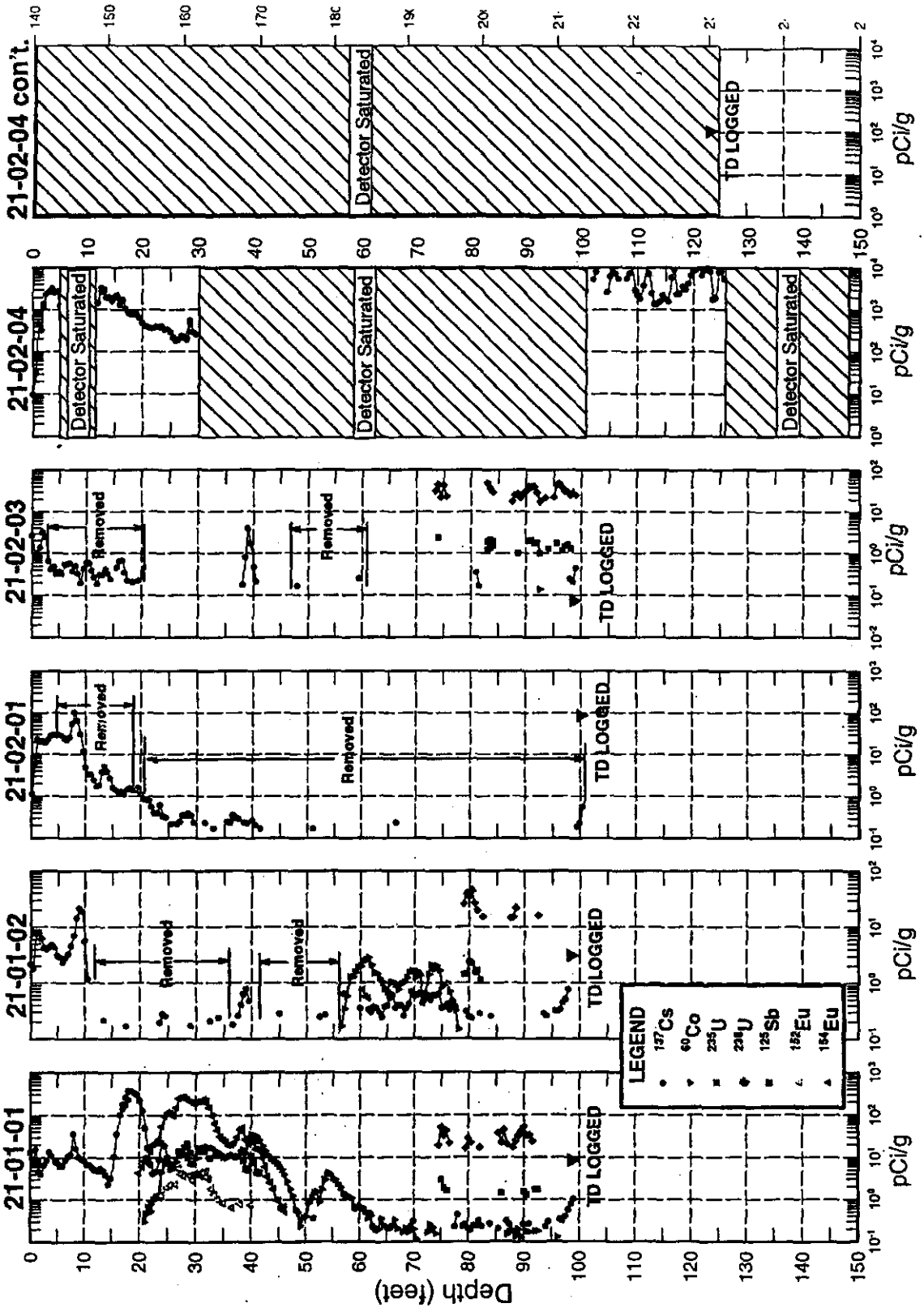


Figure E-16. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-102 (sheet 1).

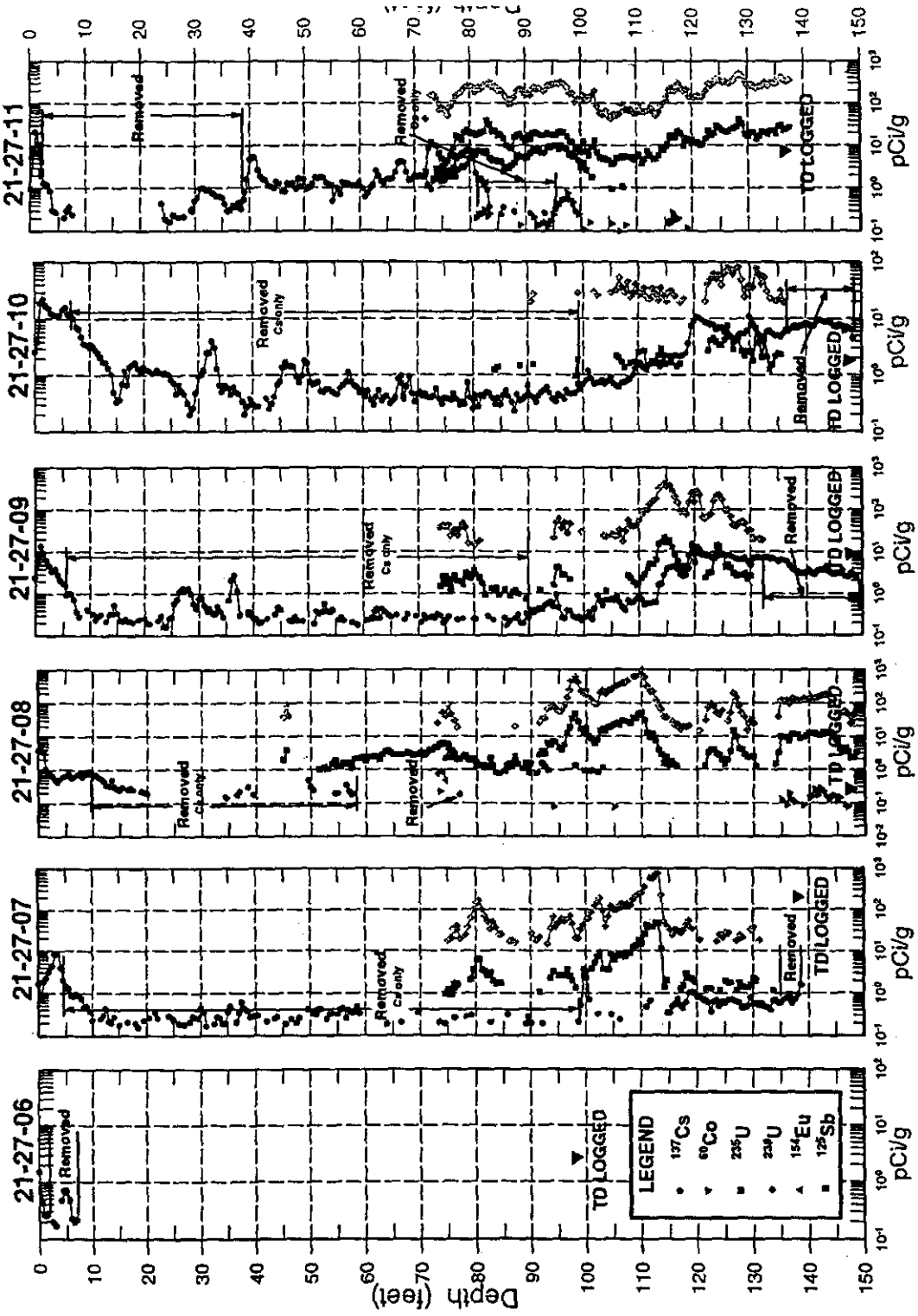


Figure E-16. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-102 (sheet 2).

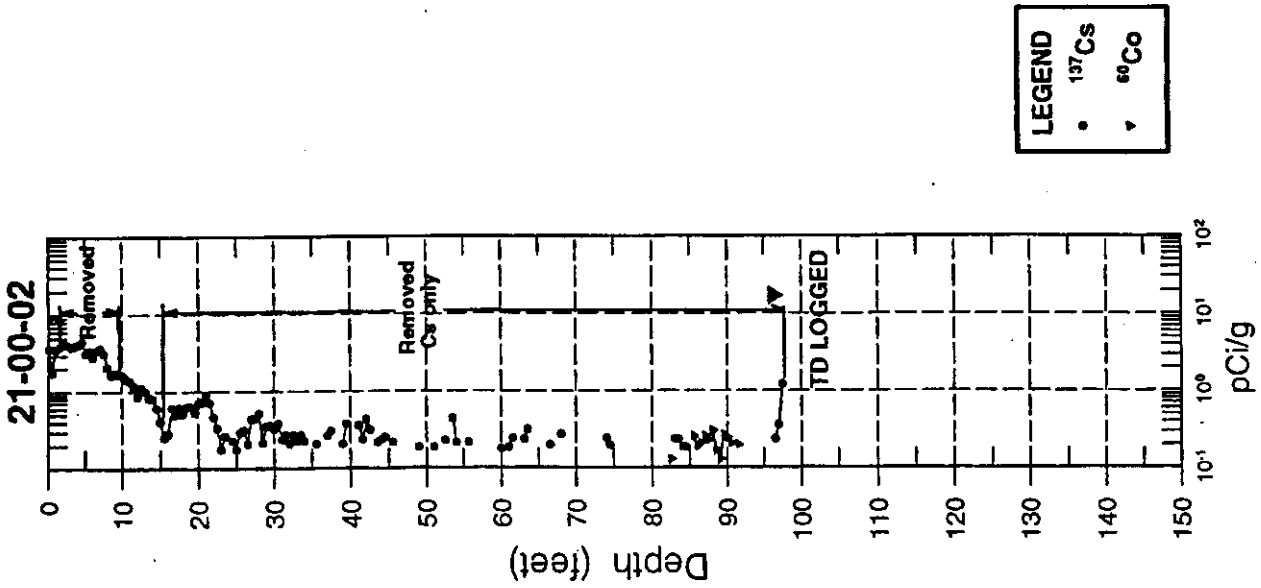


Figure E-17. Correlation Plot of ^{137}Cs, ^{60}Co, ^{238}U, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-103.

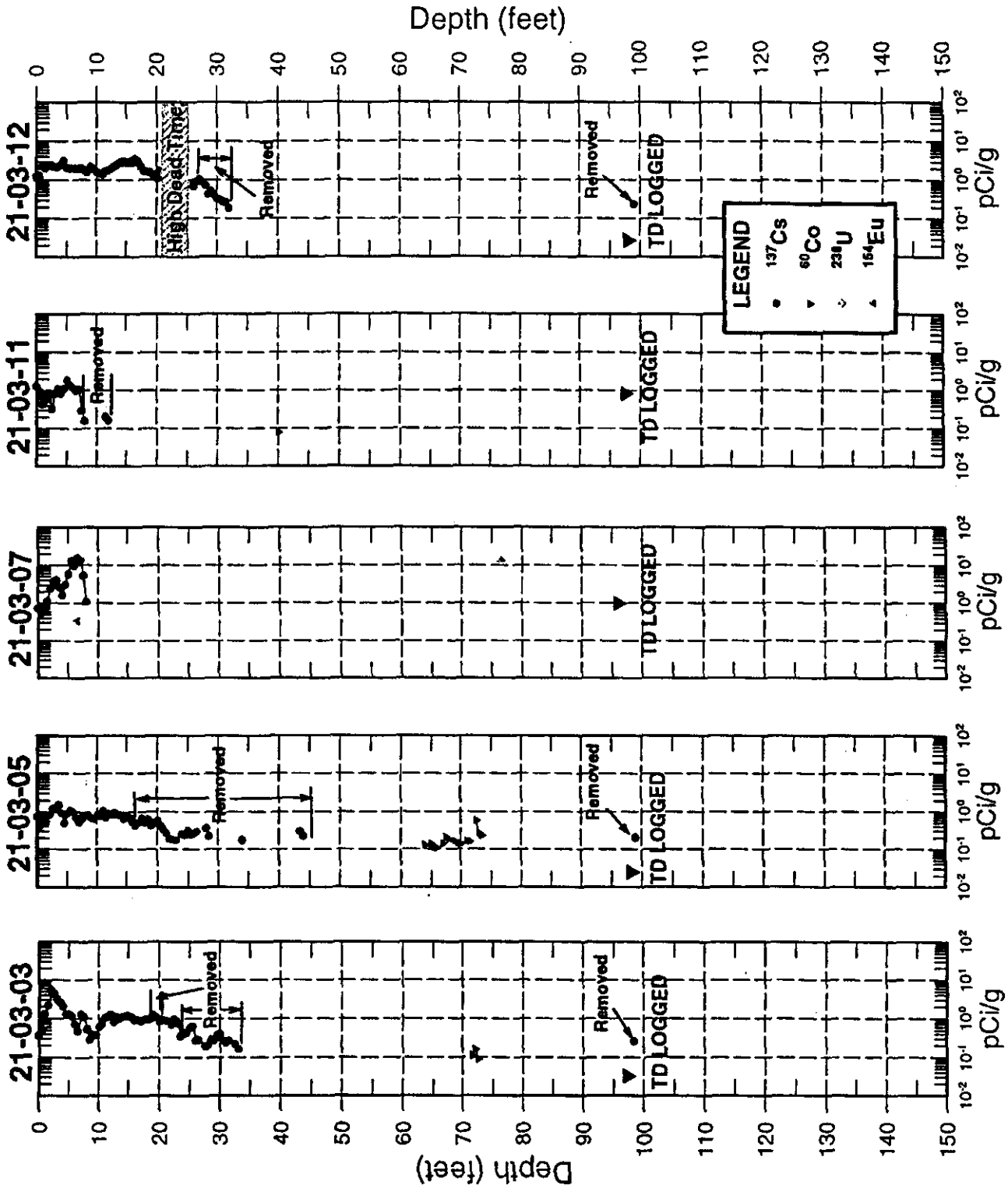


Figure E-18. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-104.

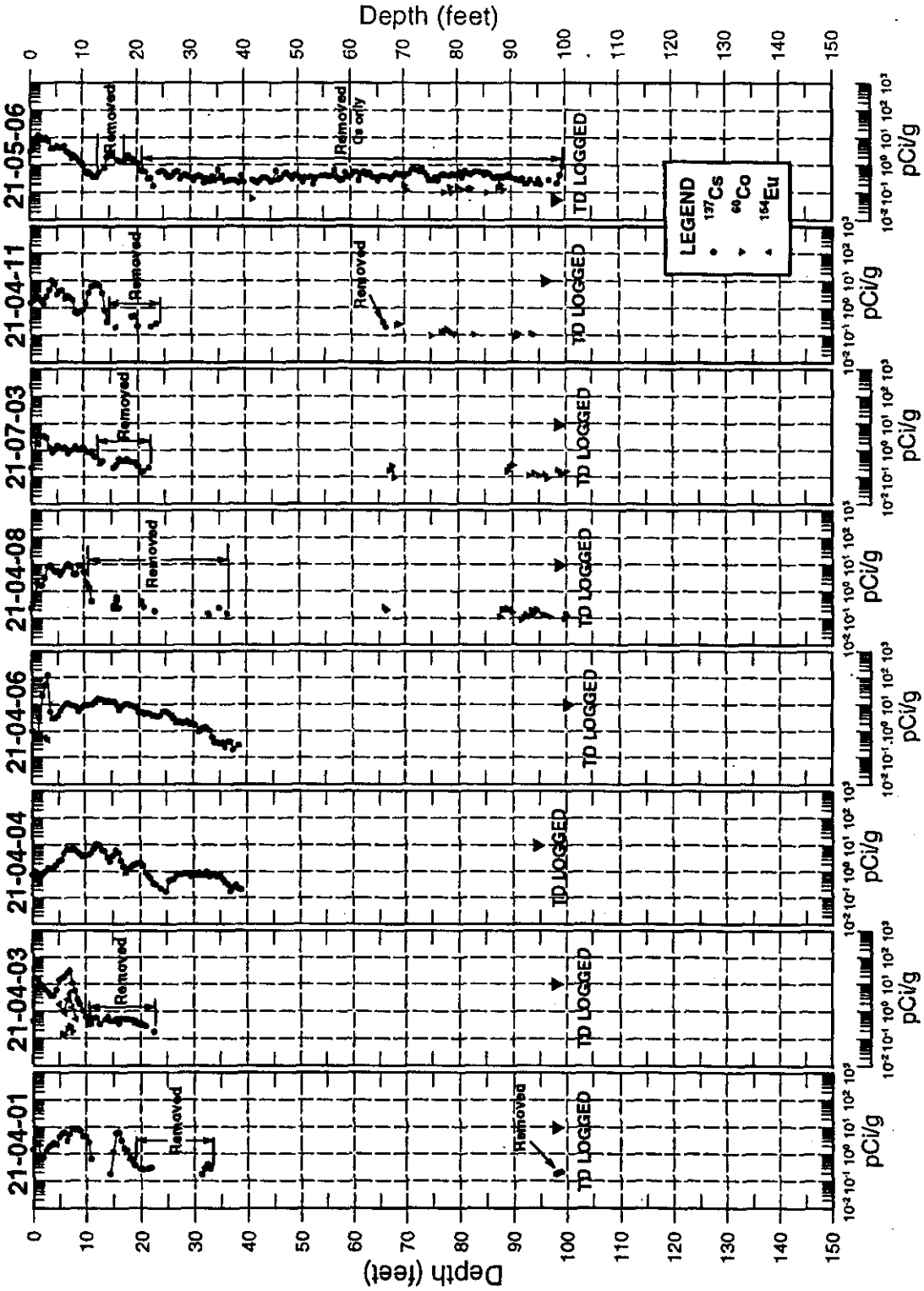


Figure E-19. Correlation Plot of ^{137}Cs, ^{60}Co, ^{152}Eu, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-105.

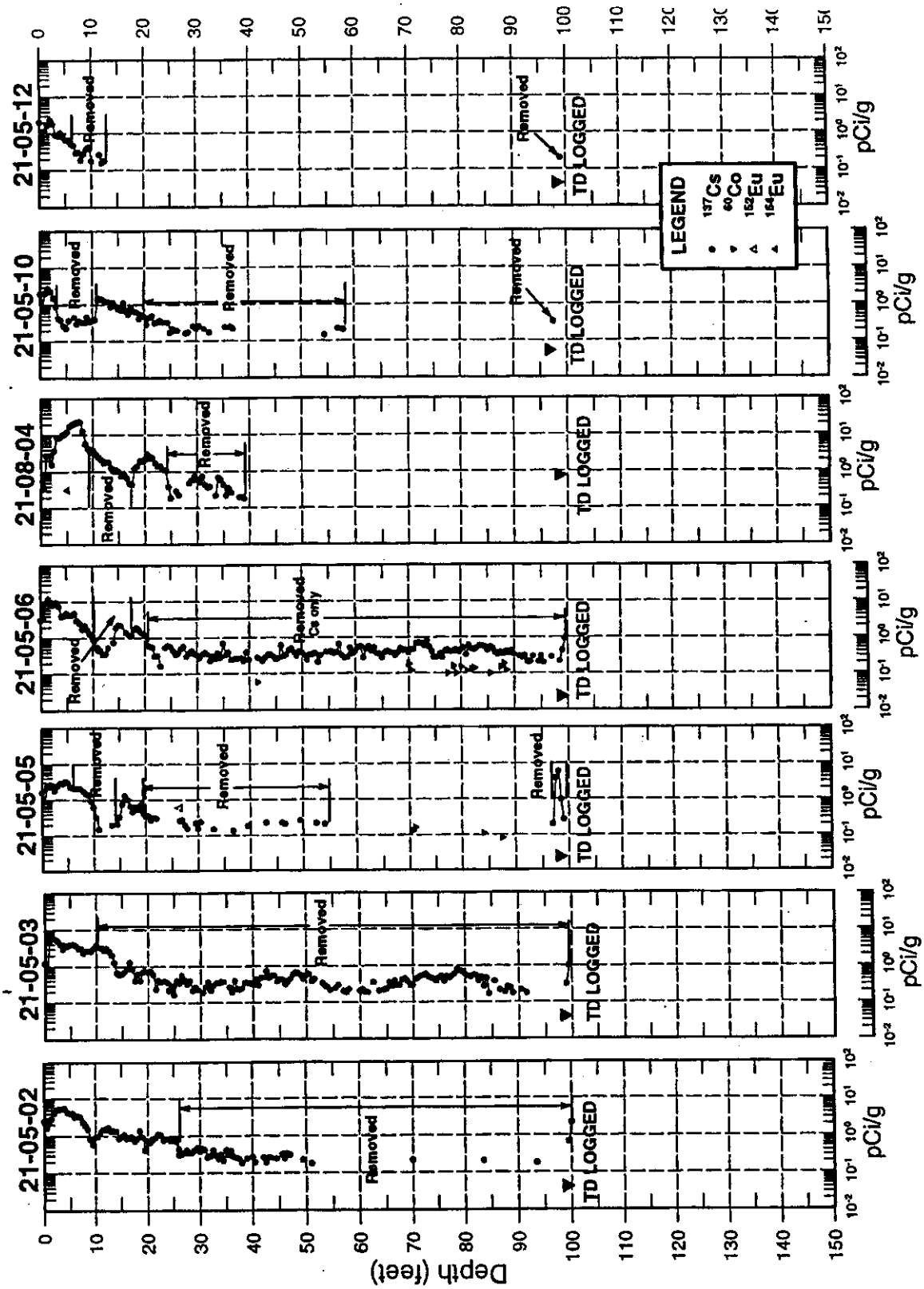


Figure E-20. Correlation Plot of ^{137}Cs, ^{125}Sb, ^{235}U, and ^{238}U Concentrations in Boreholes Surrounding Tank BX-106.

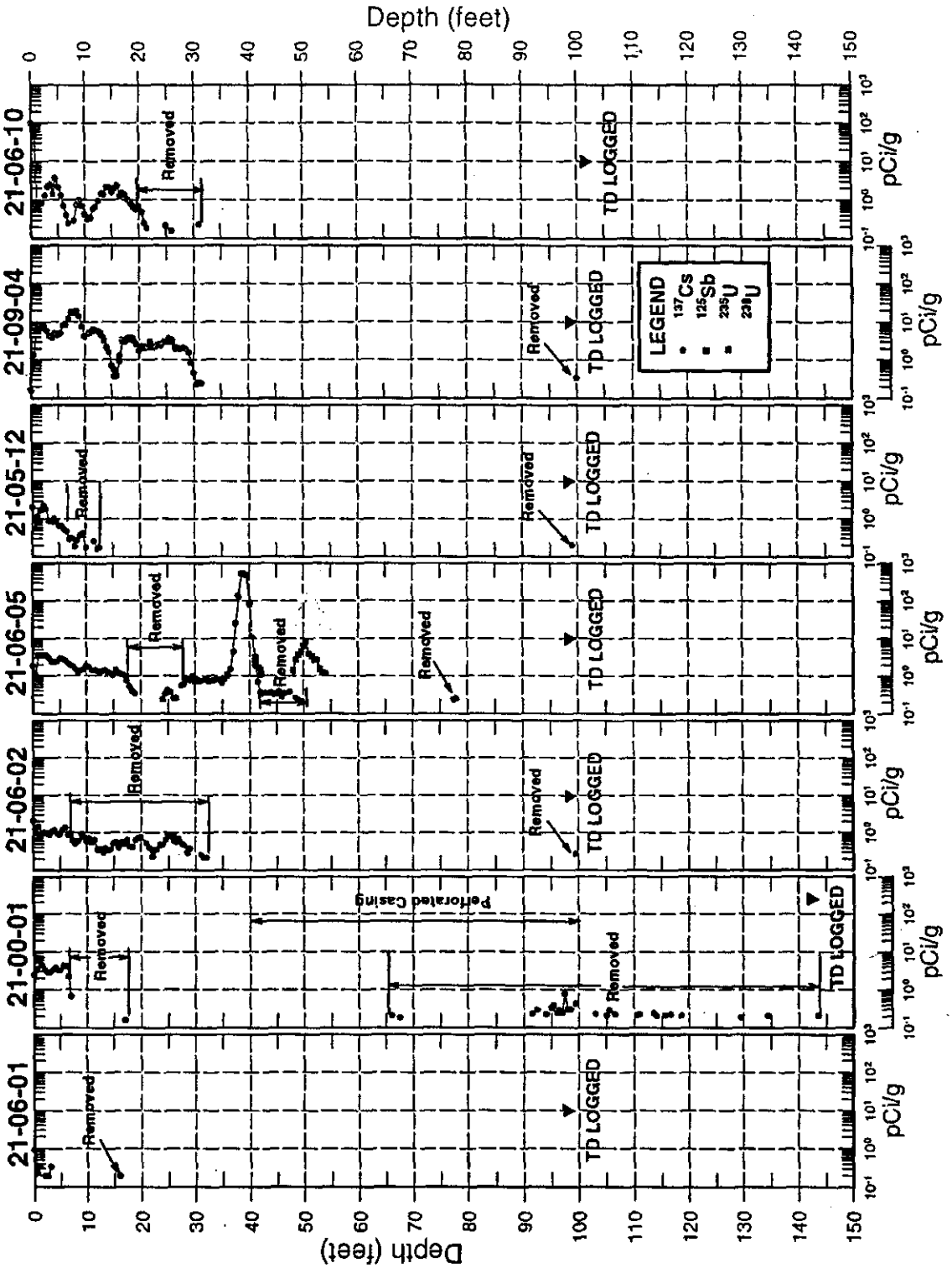


Figure E-21. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BX-107.

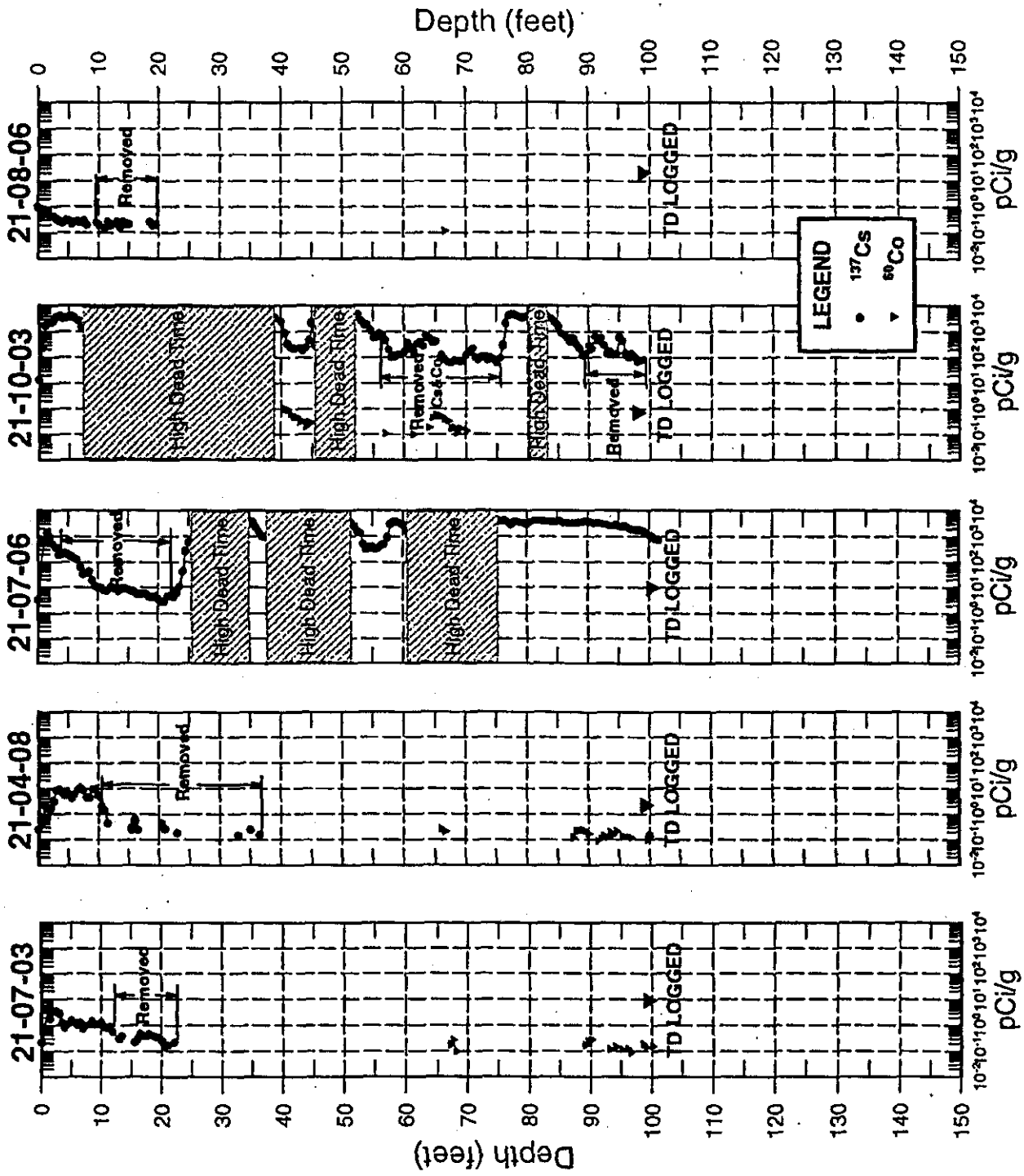


Figure E-22. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-108 (sheet 1).

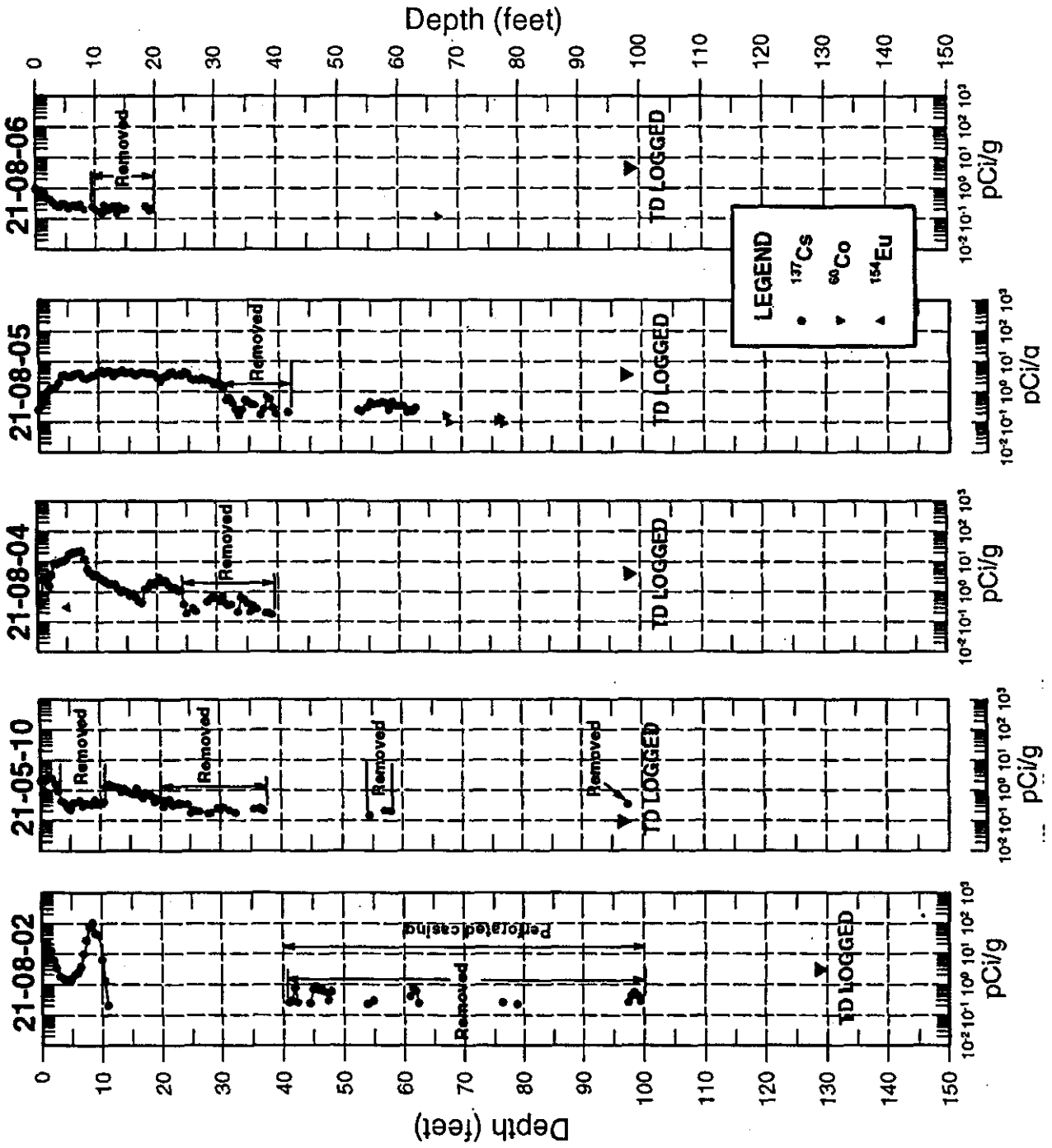


Figure E-22. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BX-108 (sheet 2).

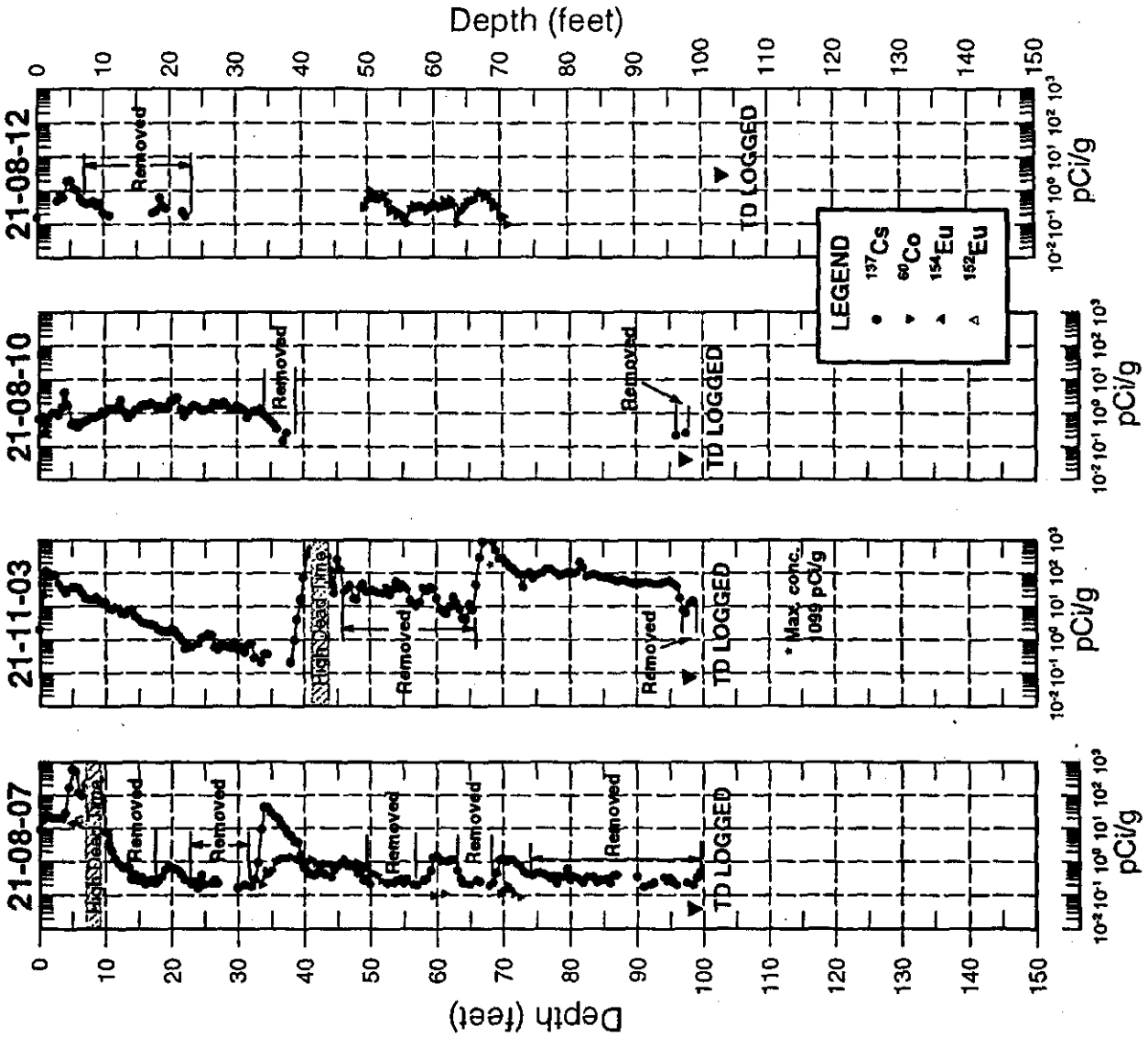


Figure E-23. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BX-109.

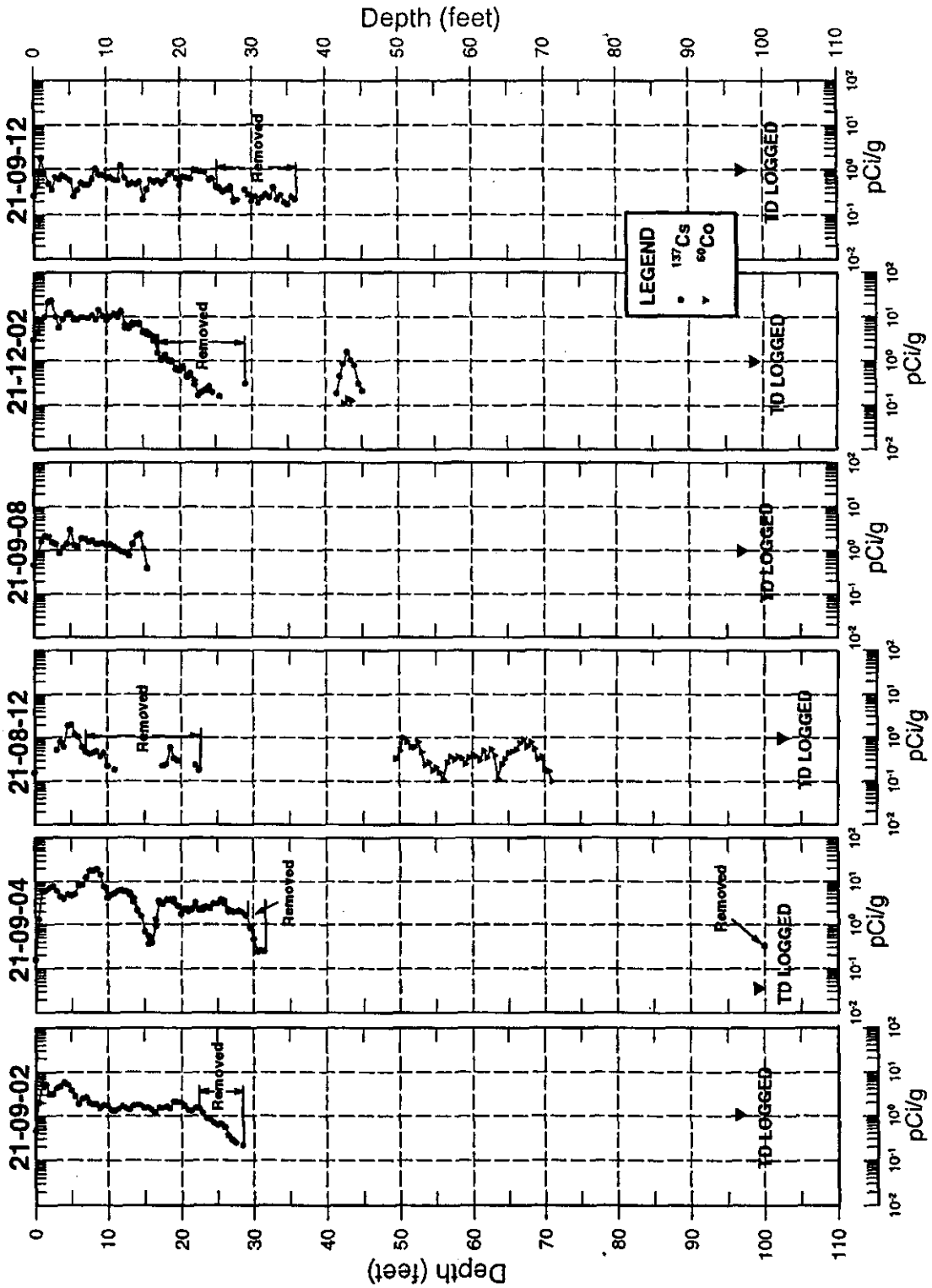


Figure E-24. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{235}U Concentrations in Boreholes Surrounding Tank BX-110.

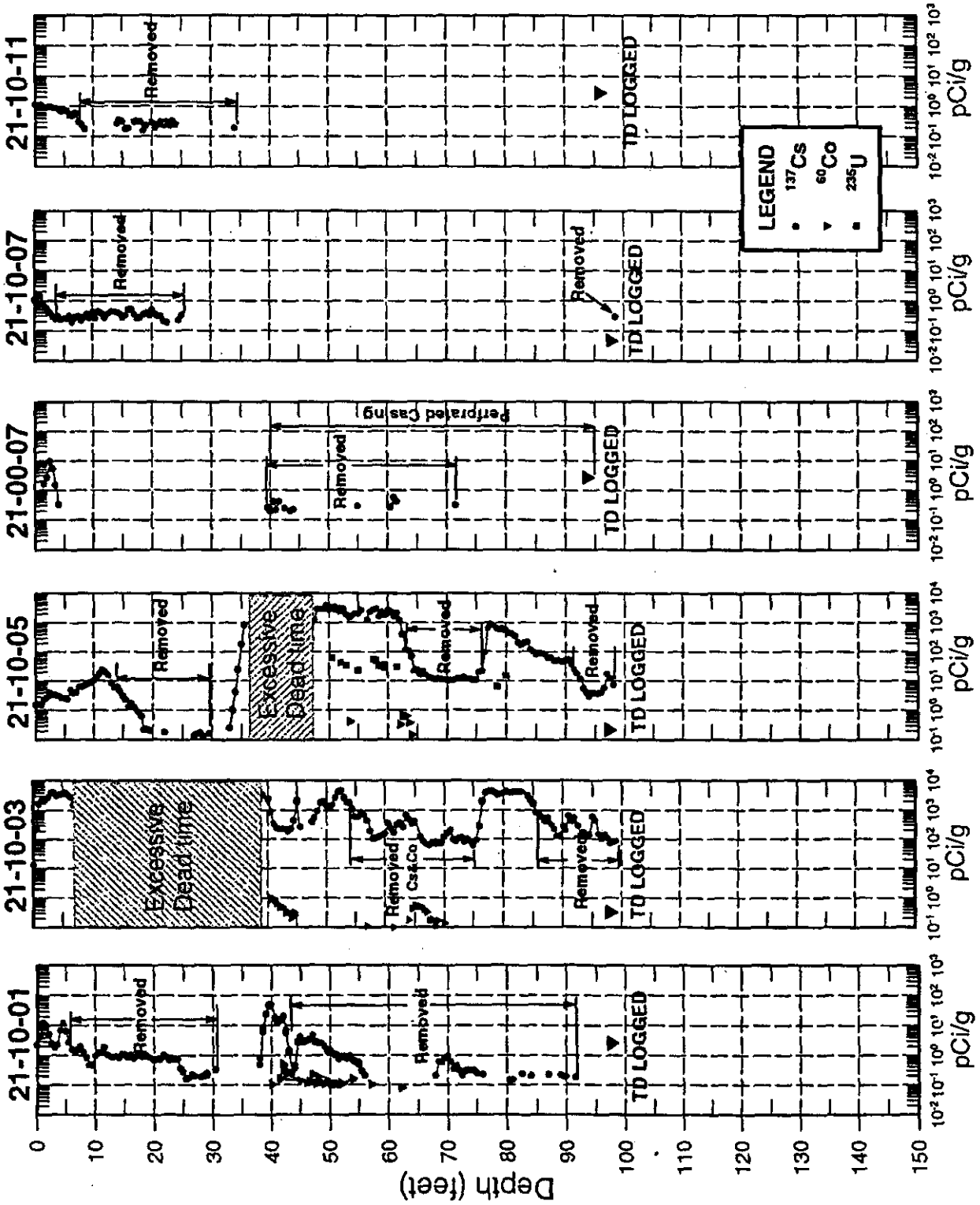


Figure E-25. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BX-111 (sheet 1).

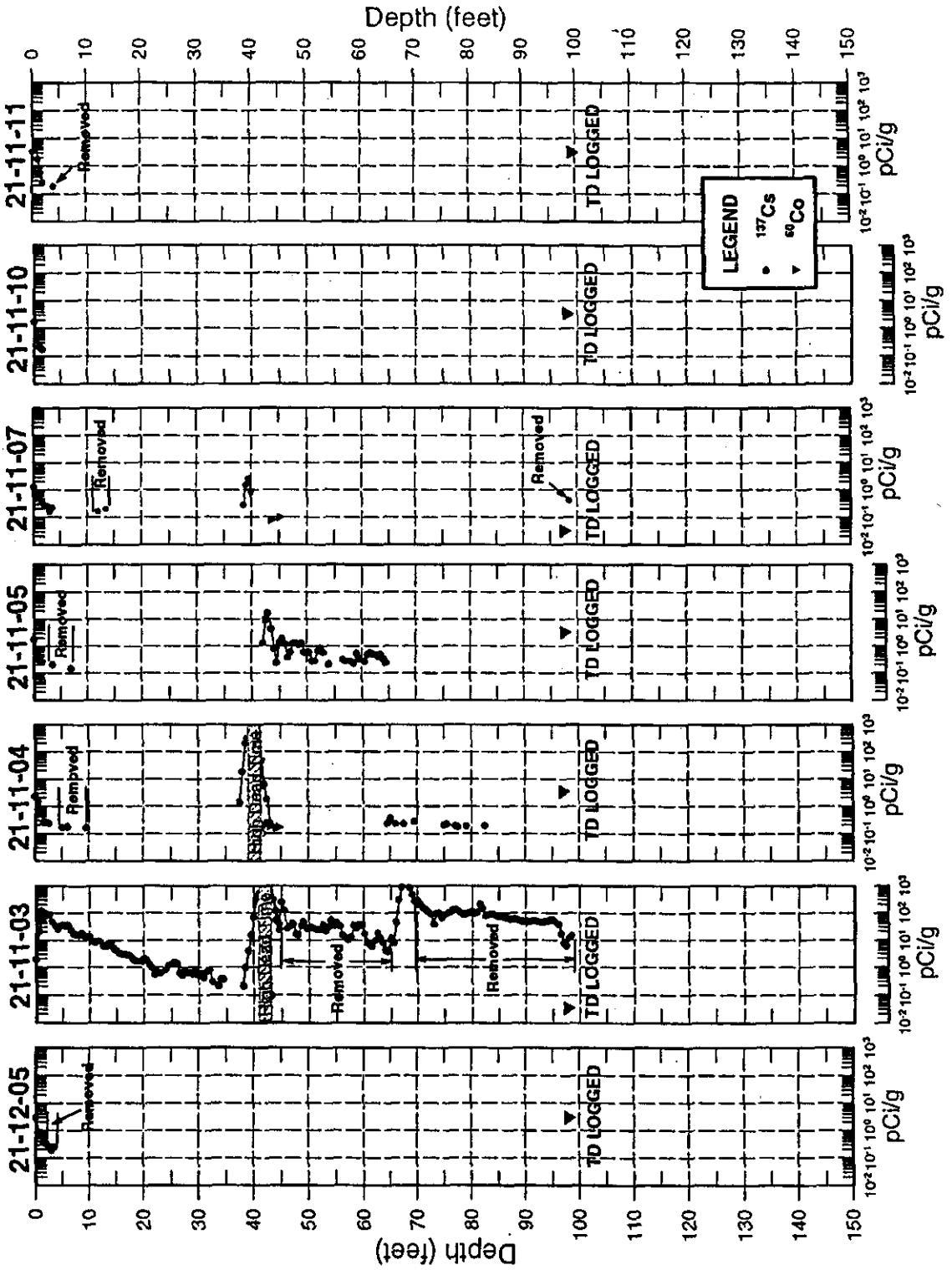


Figure E-25. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BX-111 (sheet 2).

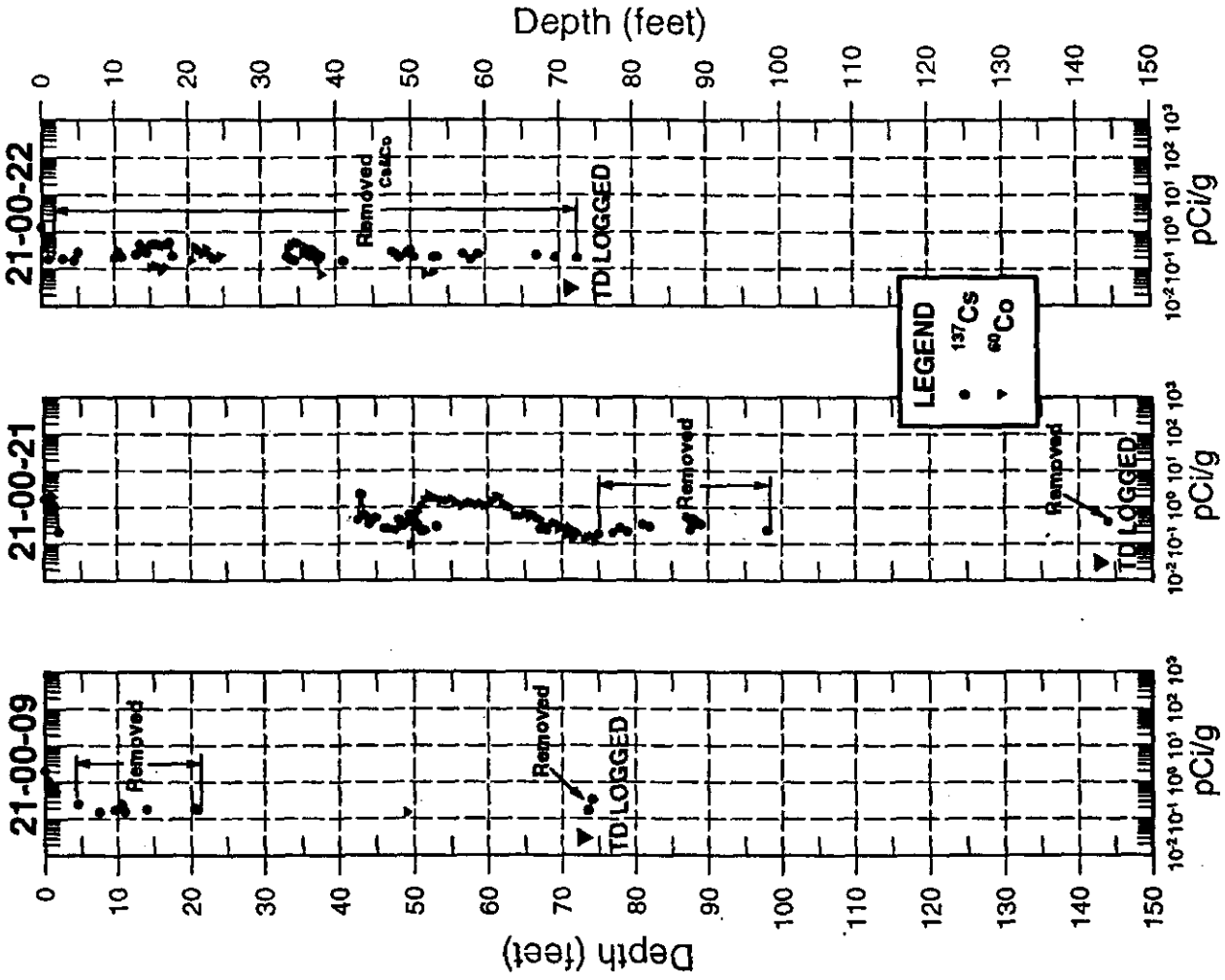
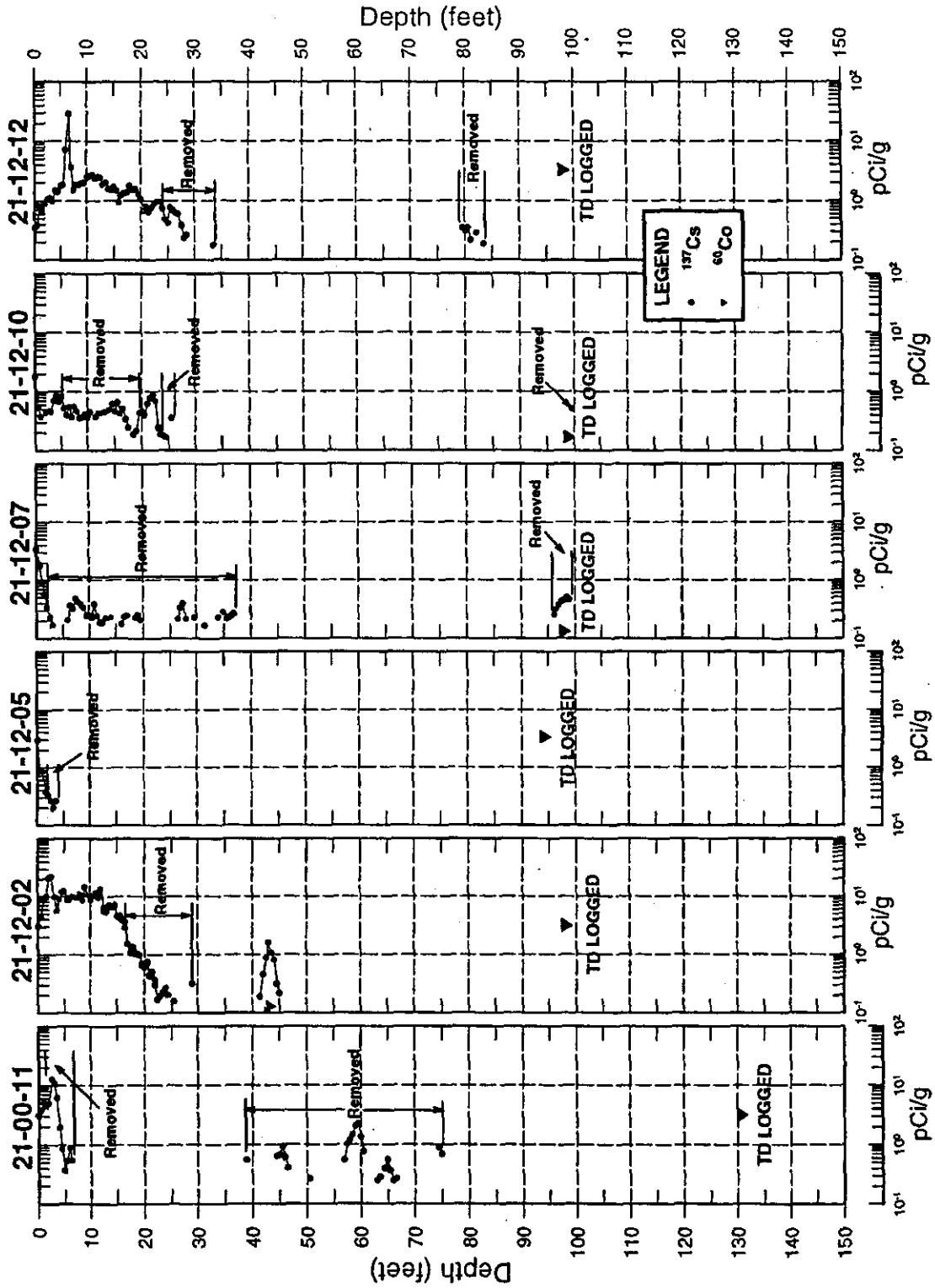


Figure E-26. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BX-112.



BY TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-27. Plan Map of the Hanford Site BY Tank Farm Showing the Locations of Monitoring Boreholes.

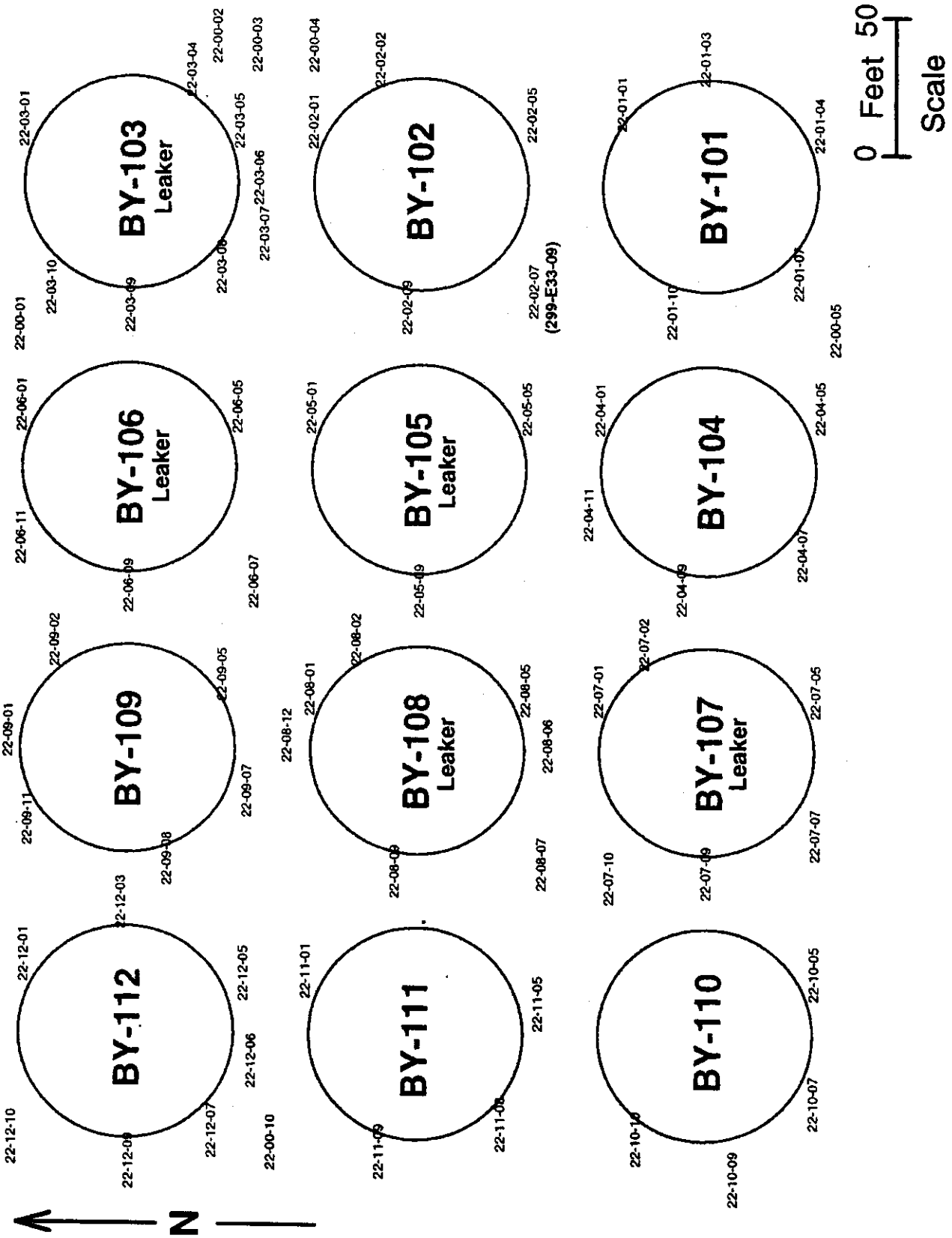


Figure E-28. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-101.

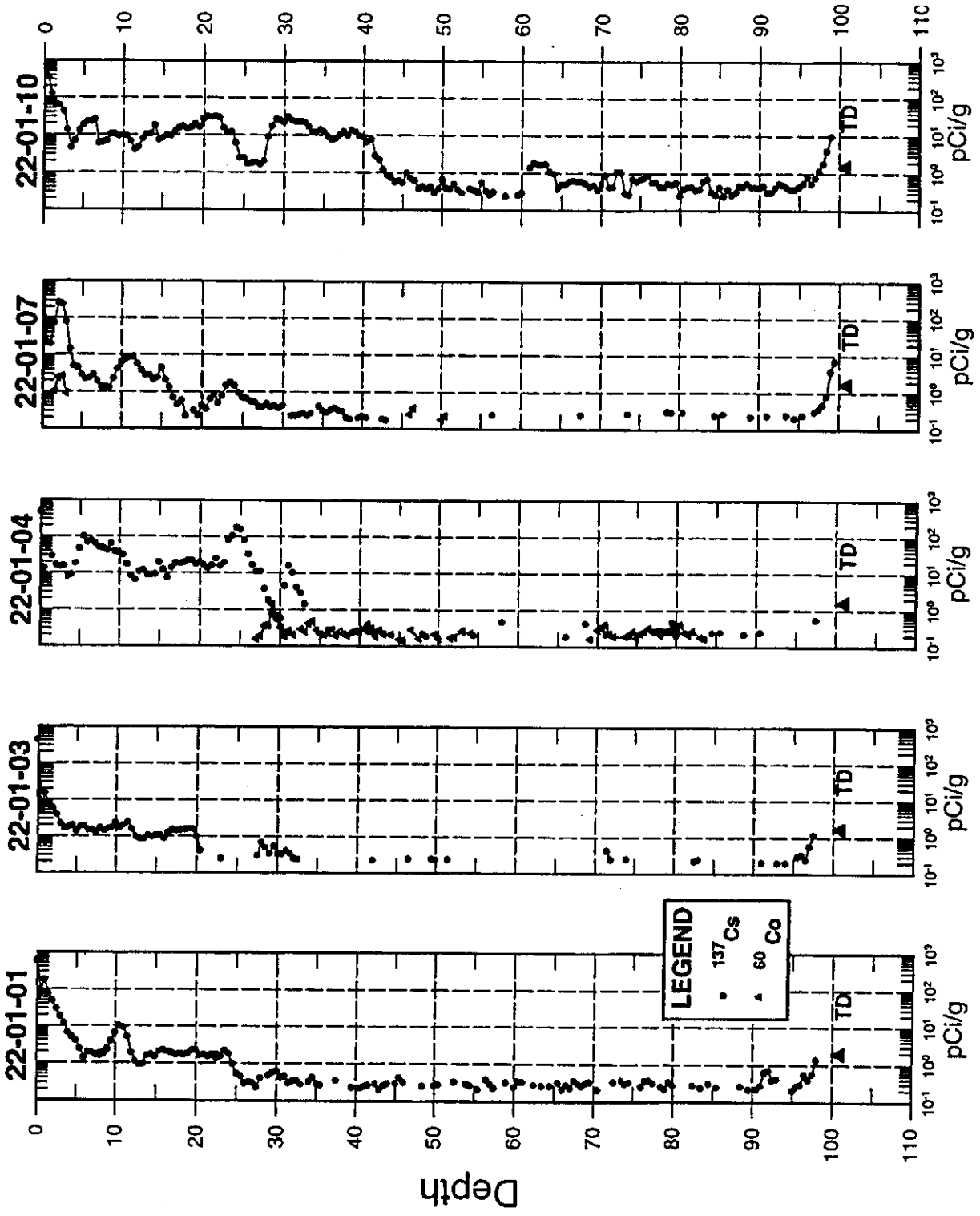


Figure E-29. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-102.

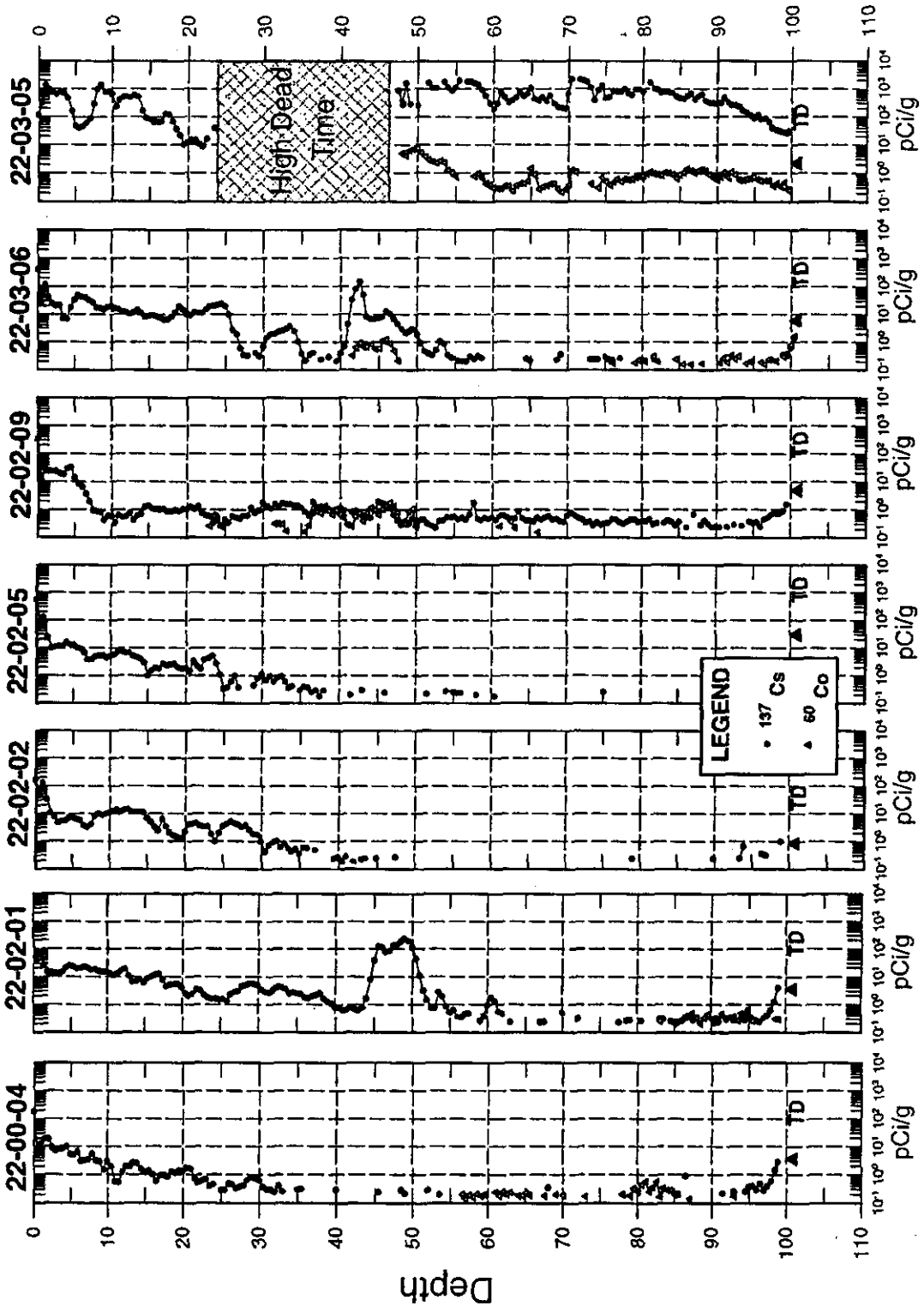


Figure E-30. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{125}Sb Concentrations in Boreholes Surrounding Tank BY-103 (sheet 1).

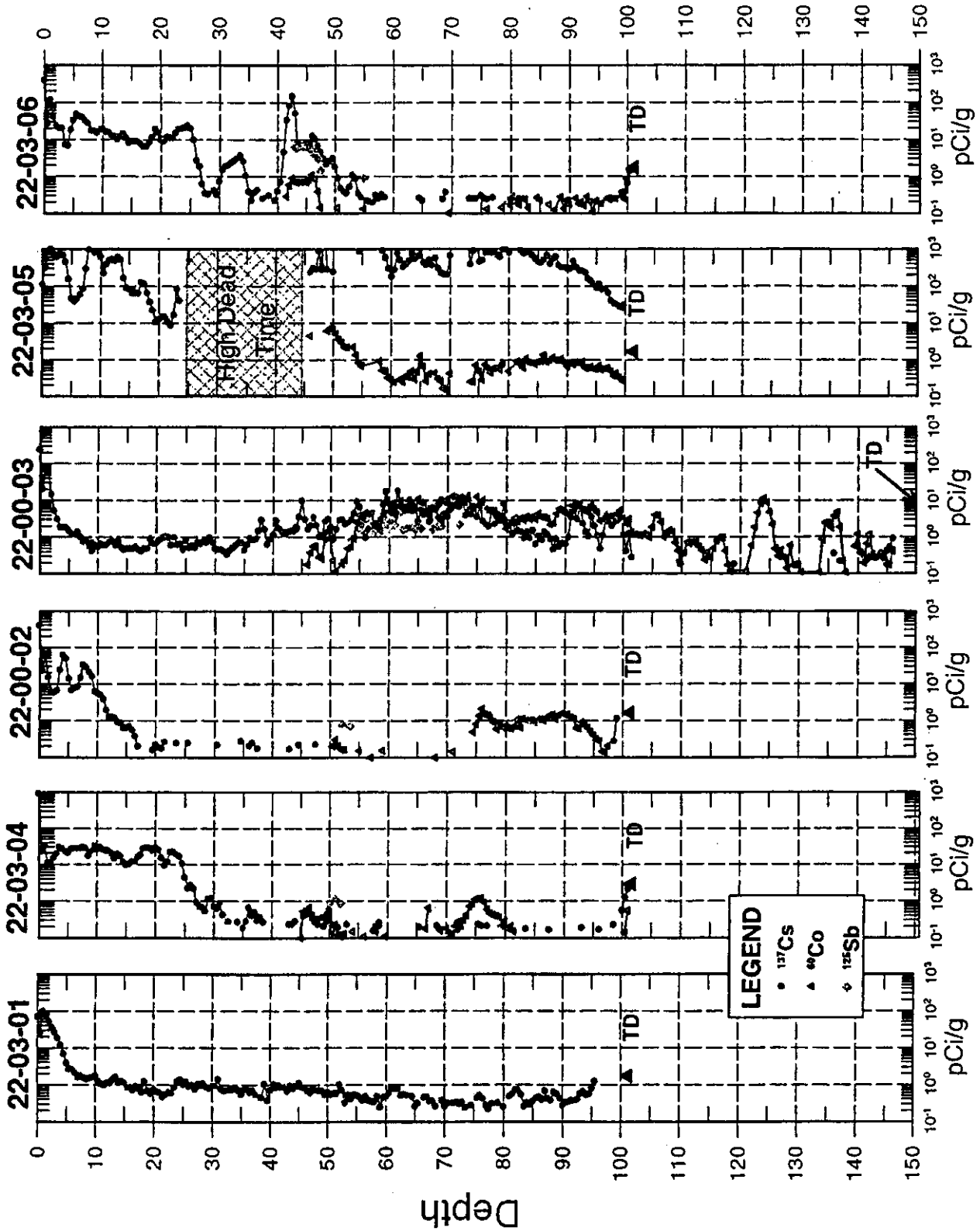


Figure E-30. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-103 (sheet 2).

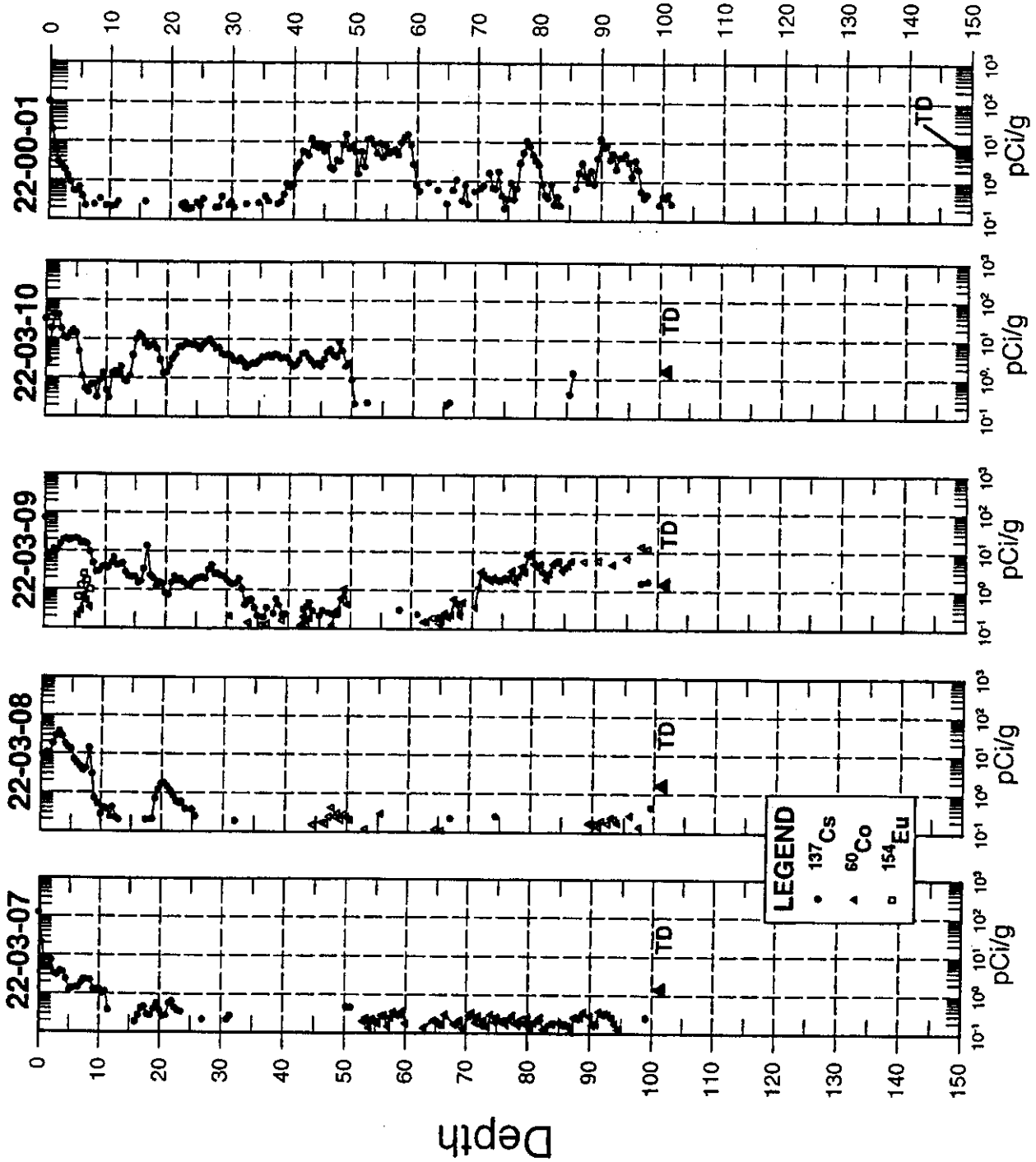


Figure E-31. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-104.

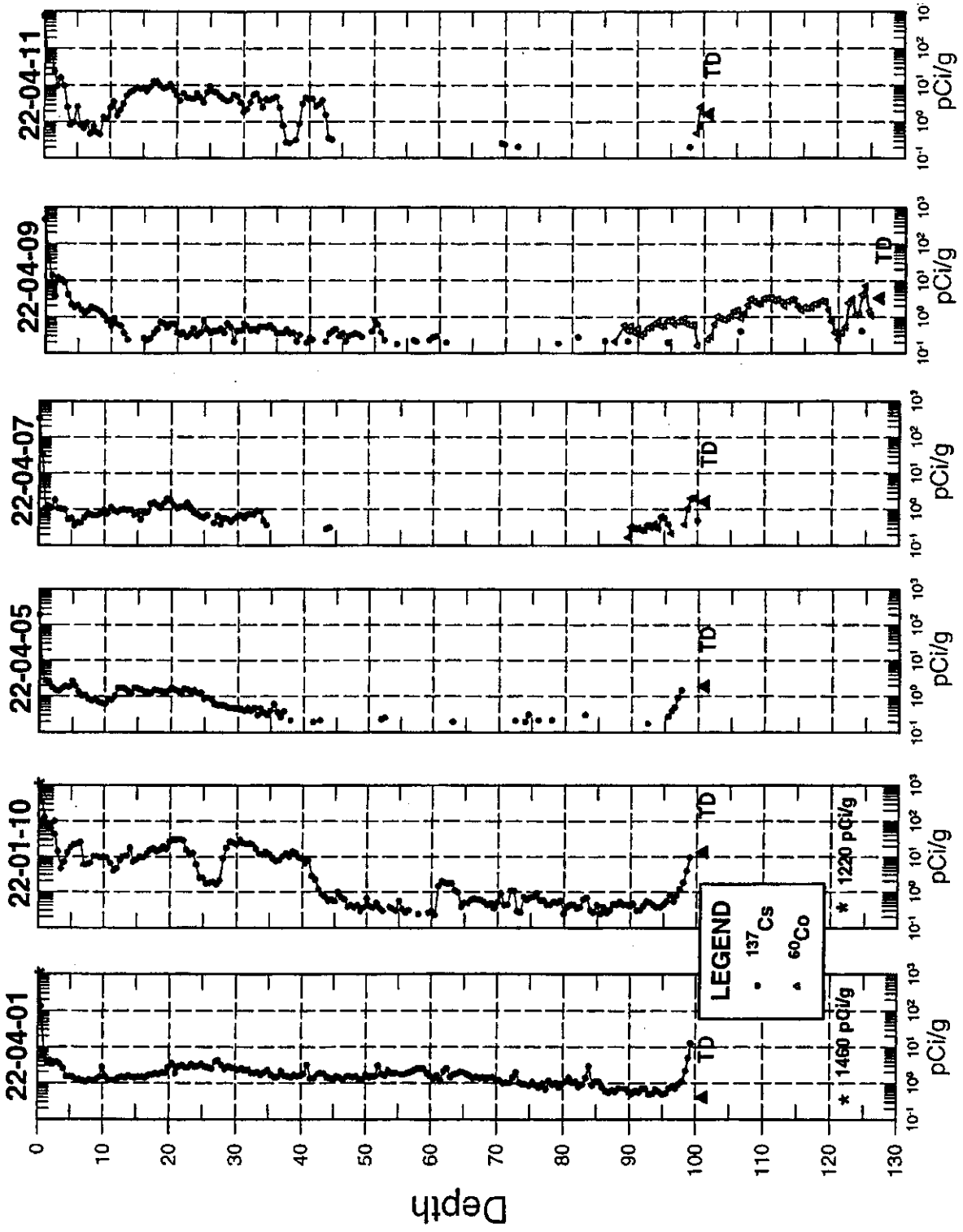


Figure E-32. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-105.

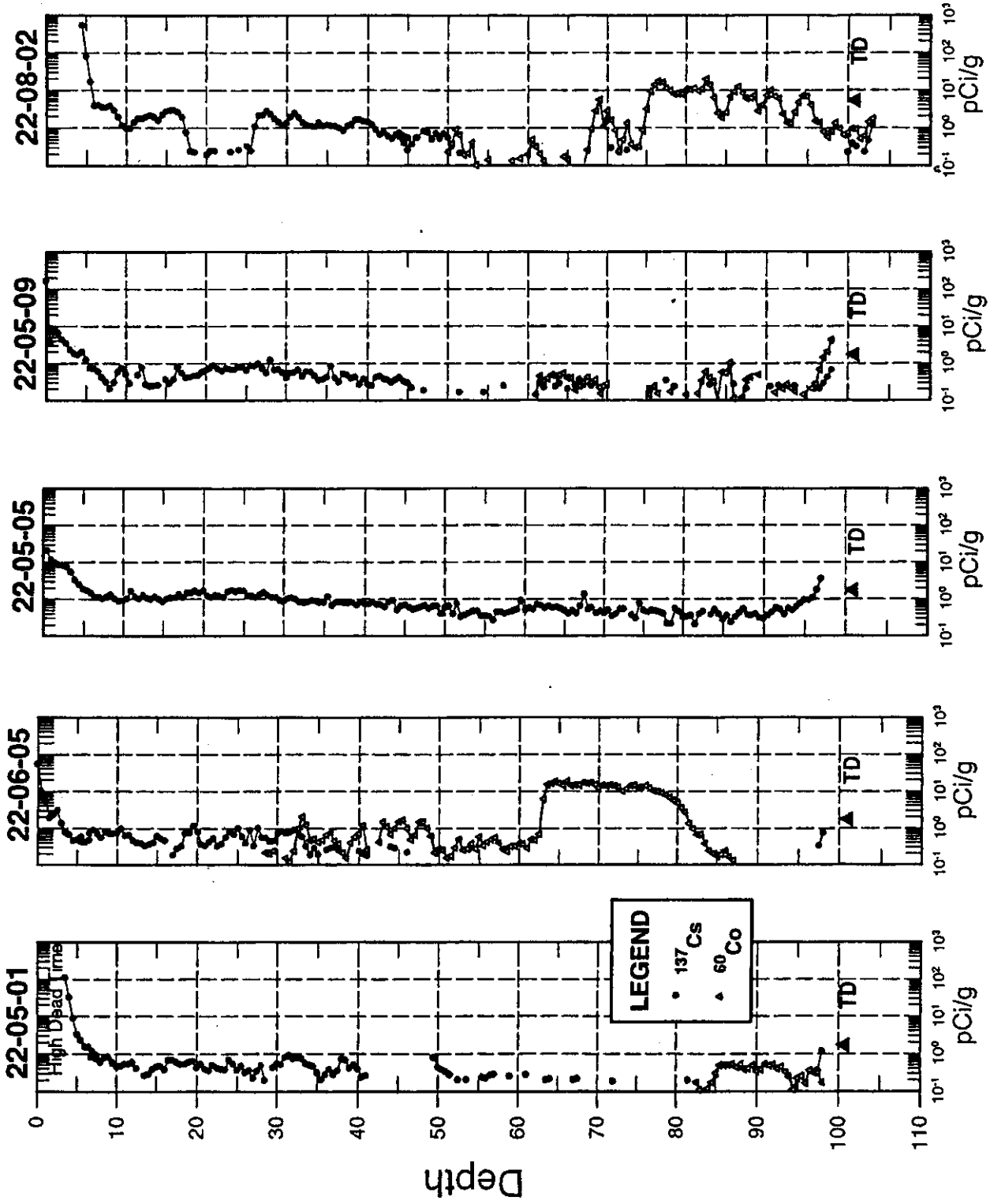


Figure E-33. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-106.

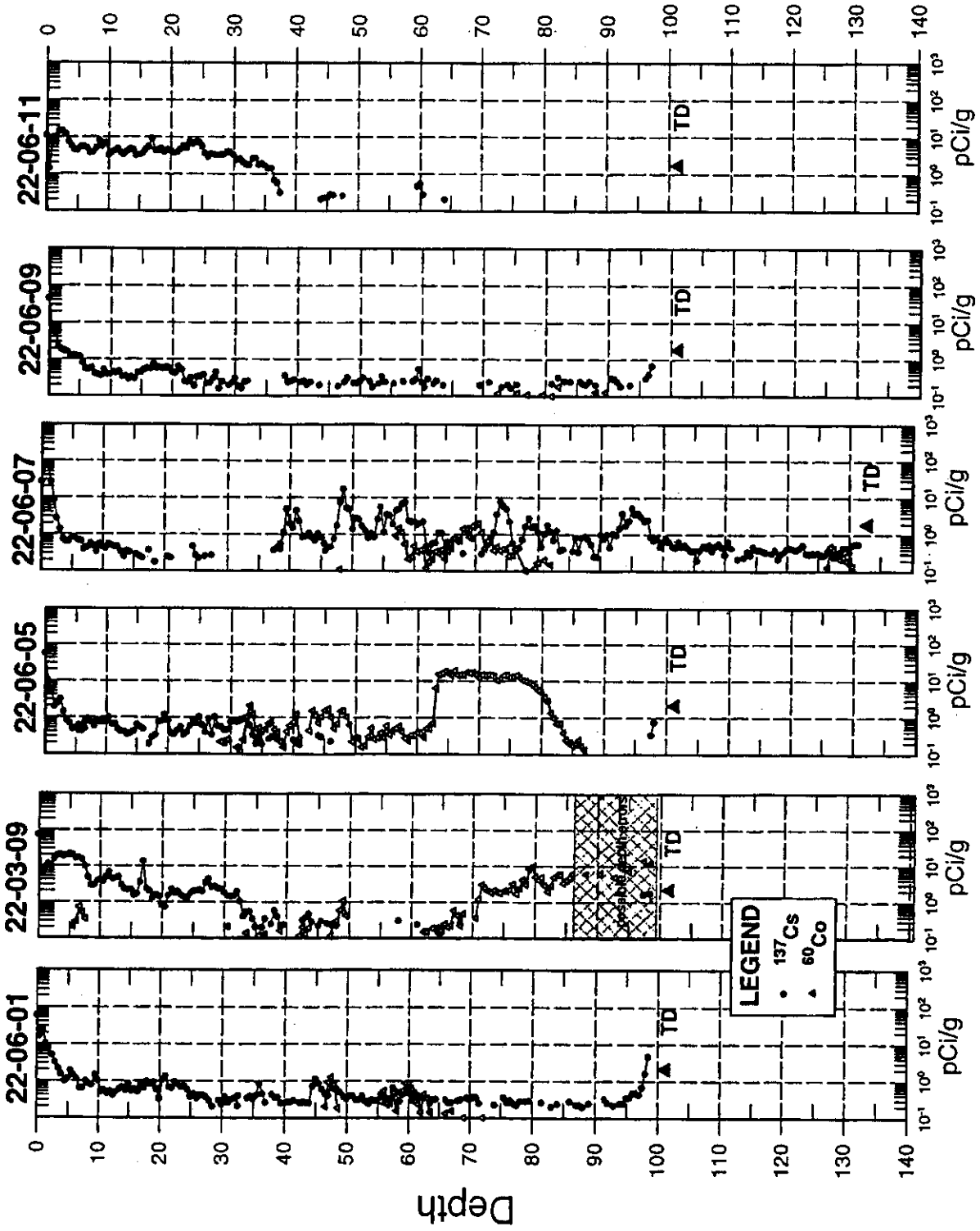


Figure E-34. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-107.

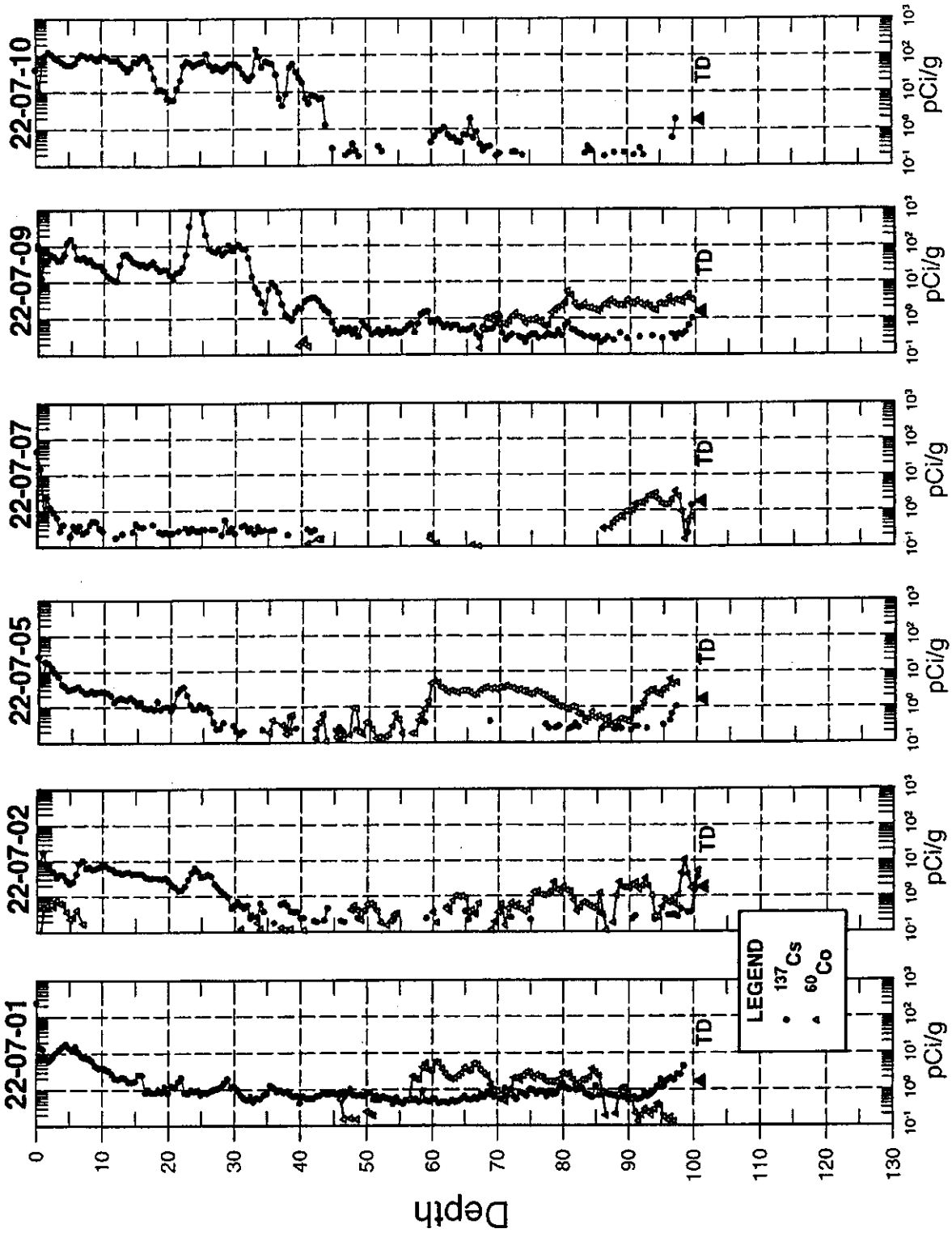


Figure E-35. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in I
Surrounding Tank BY-108.

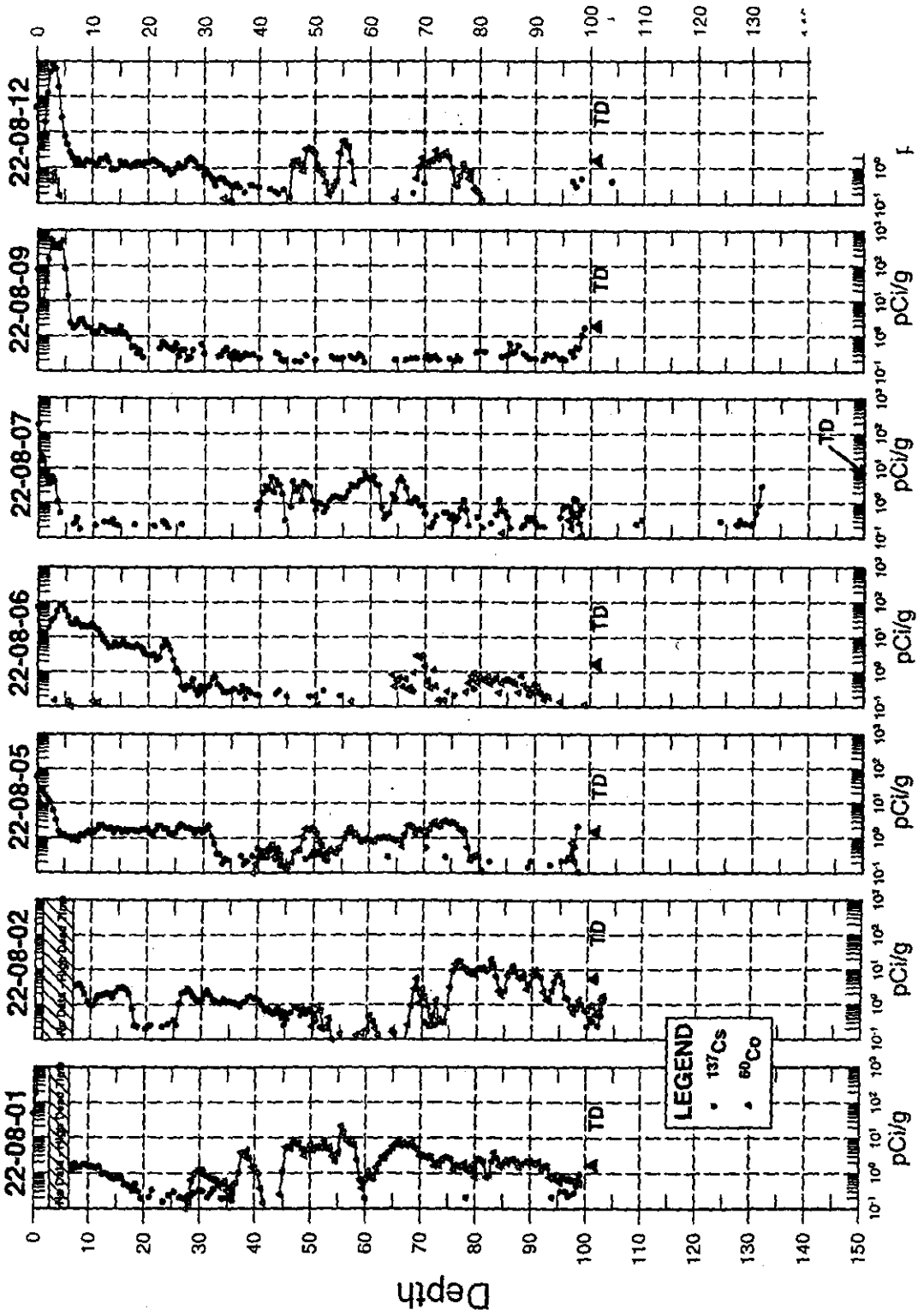


Figure E-36. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-109.

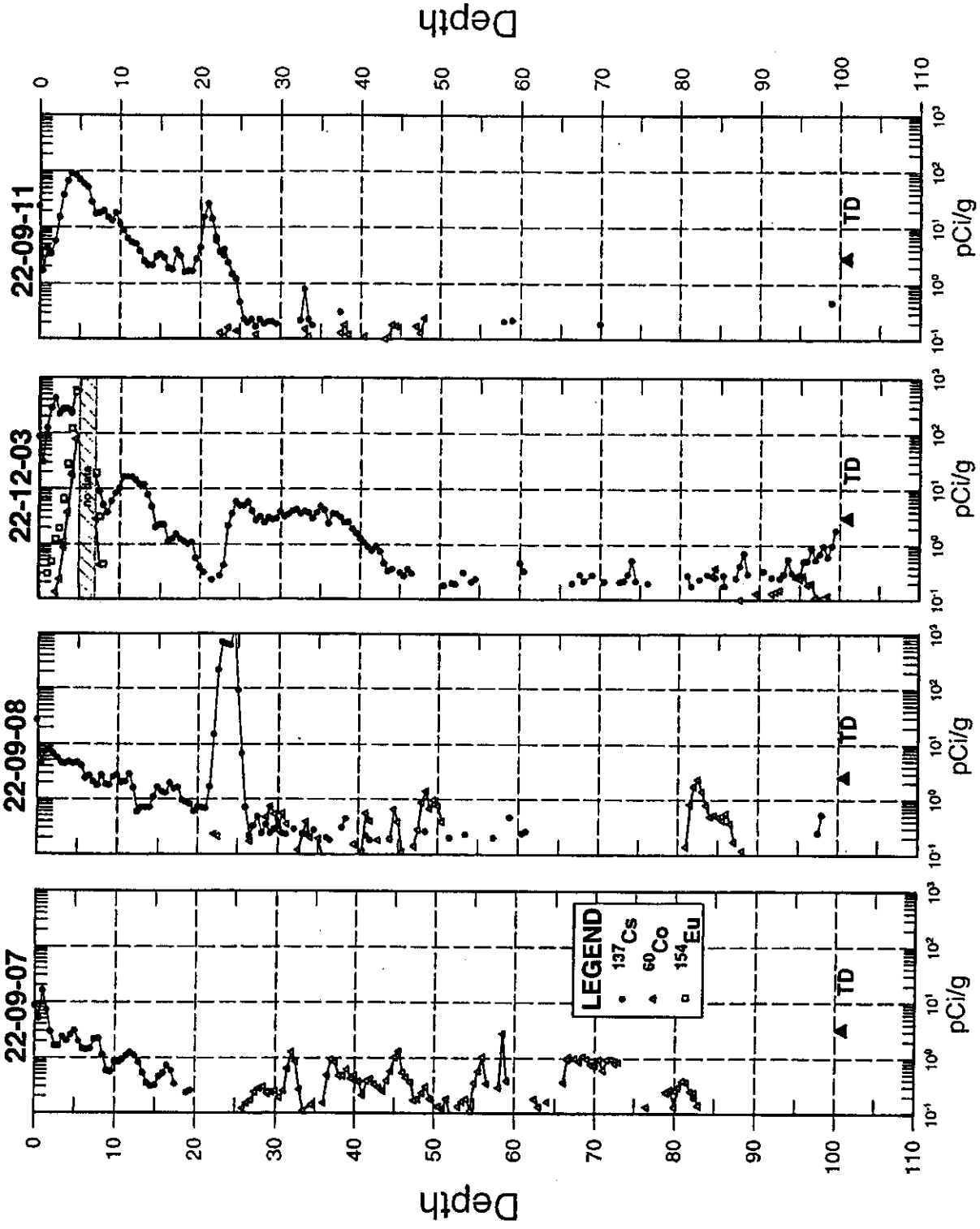


Figure E-37. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-109.

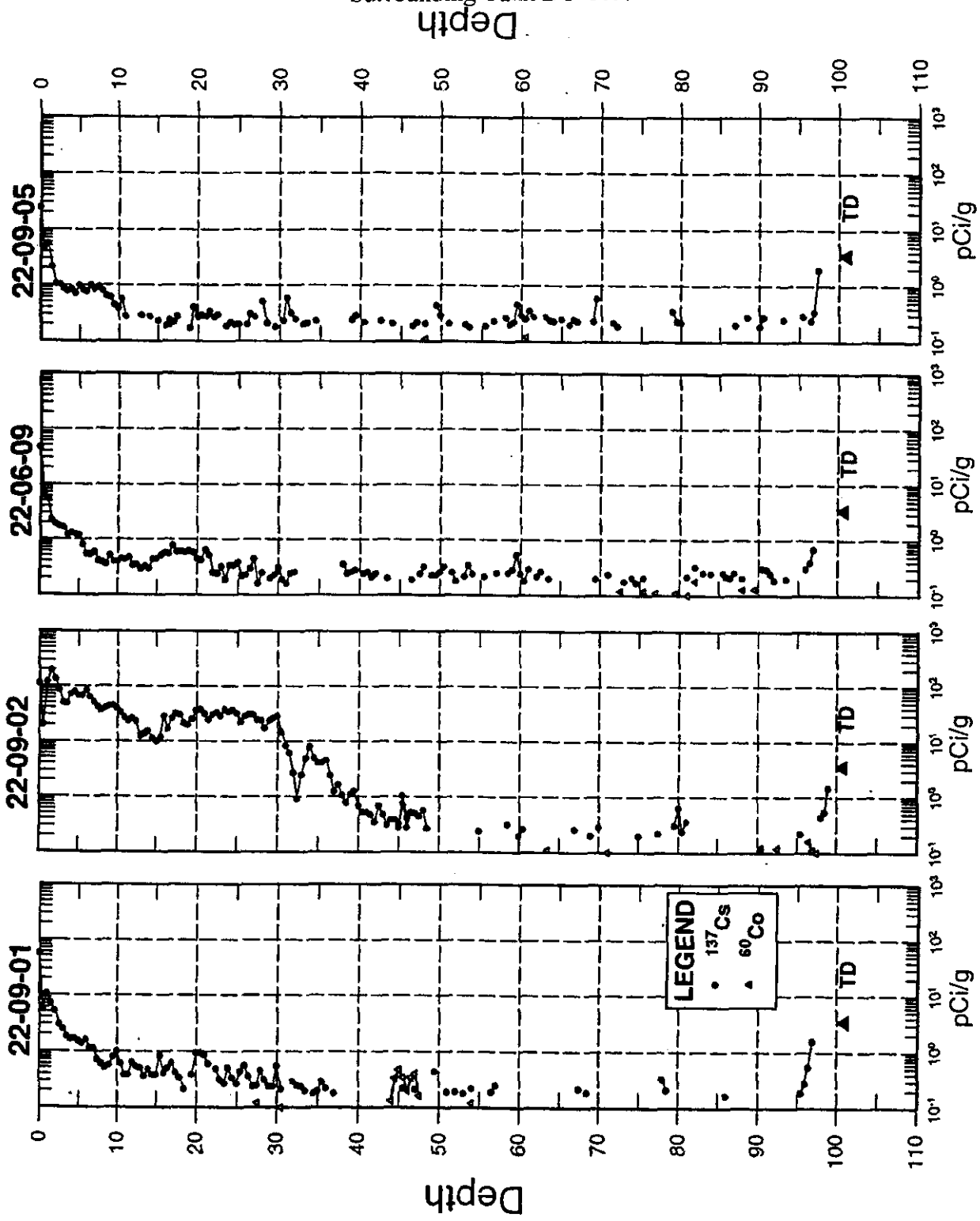


Figure E-38. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-110.

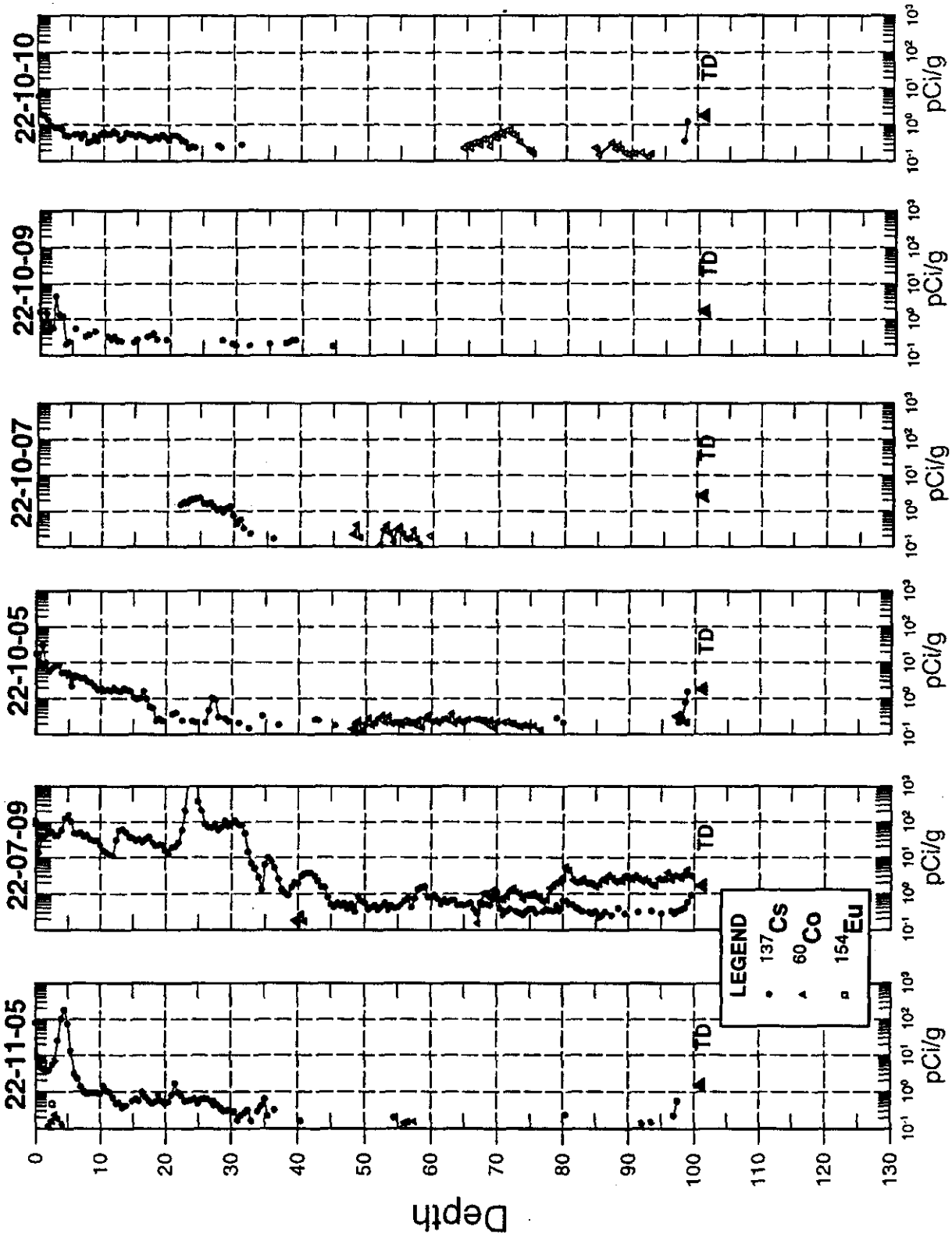


Figure E-39. Correlation Plot of ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{234}Pa Concentrations in Boreholes Surrounding Tank BY-111.

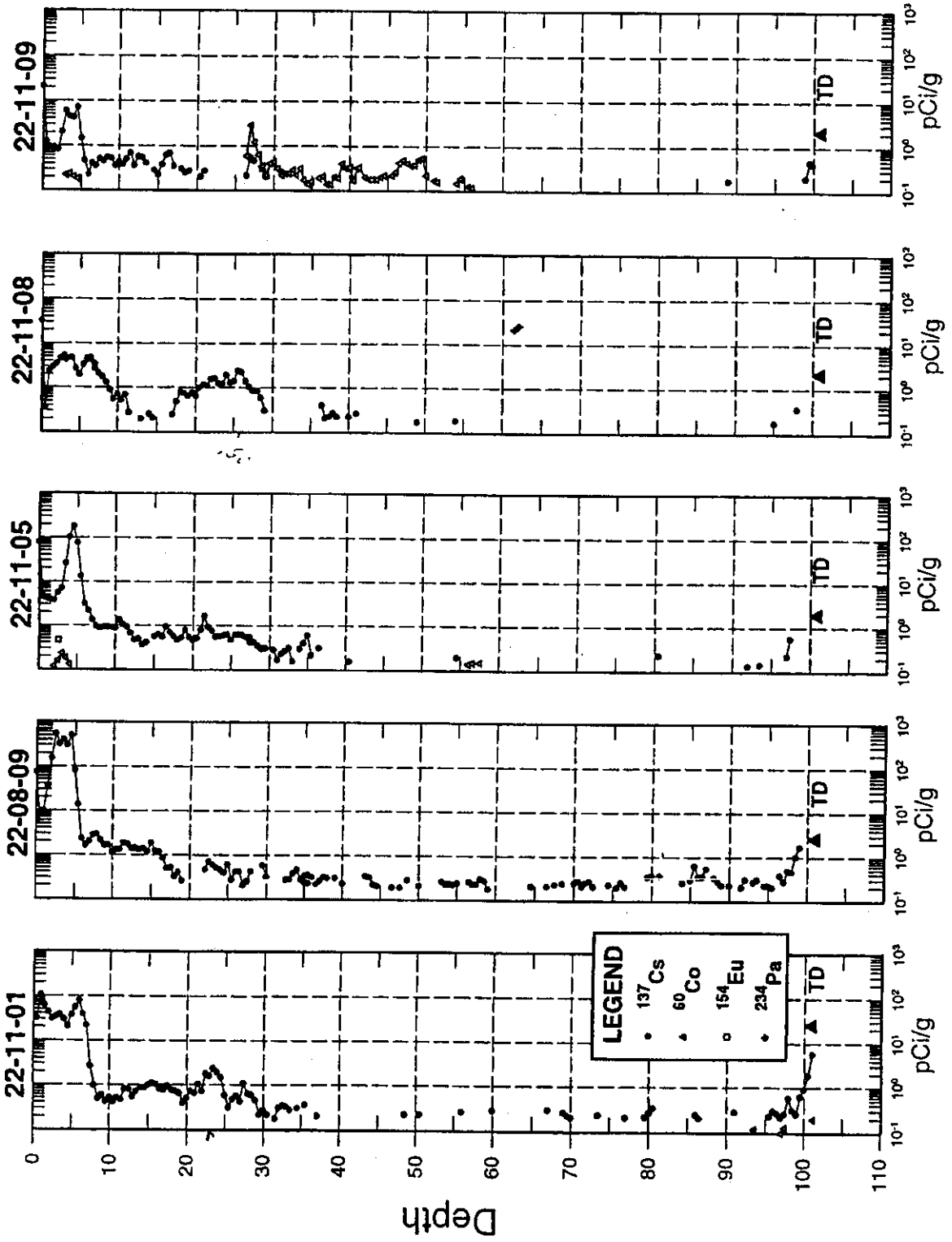


Figure E-40. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-112 (sheet 1).

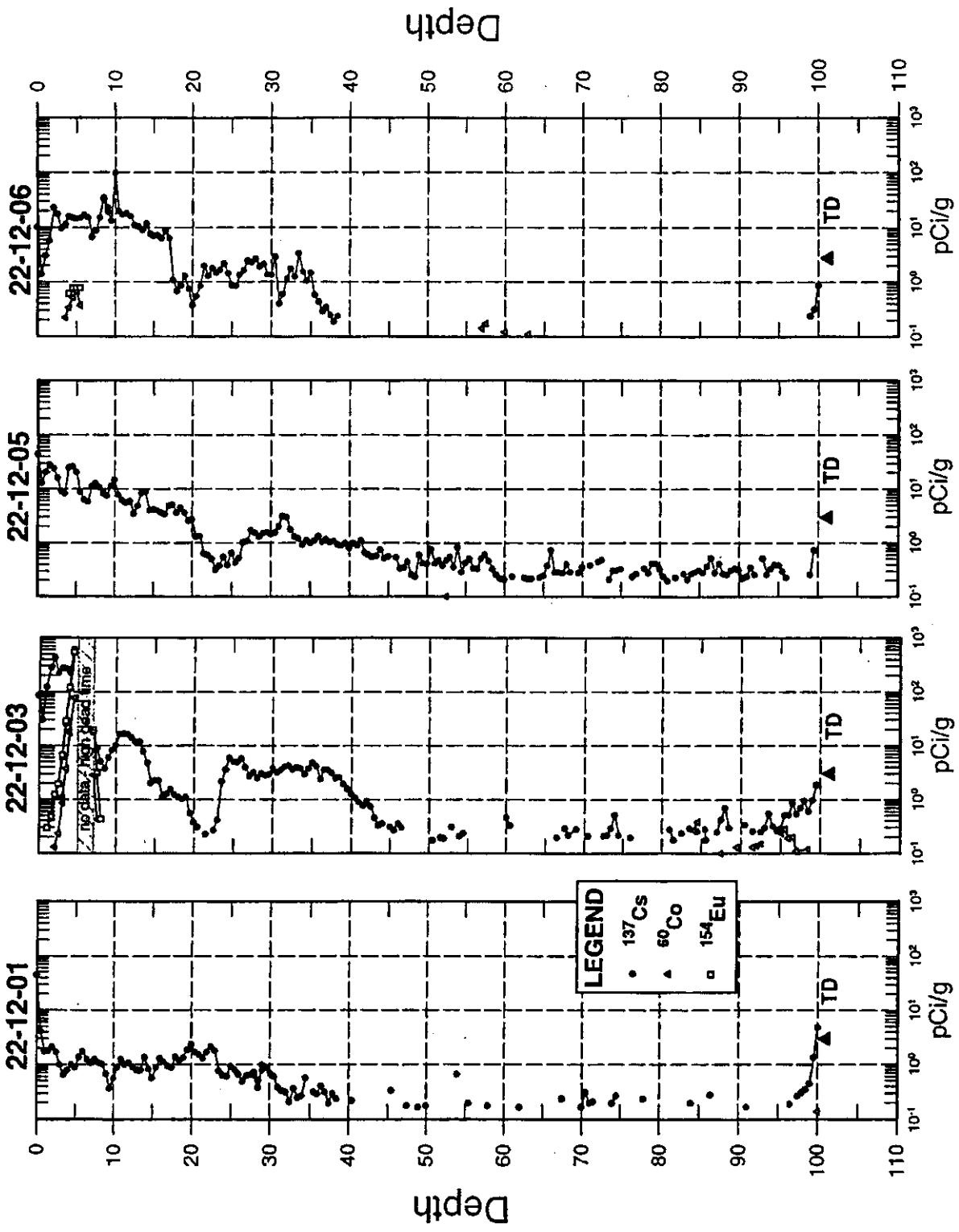
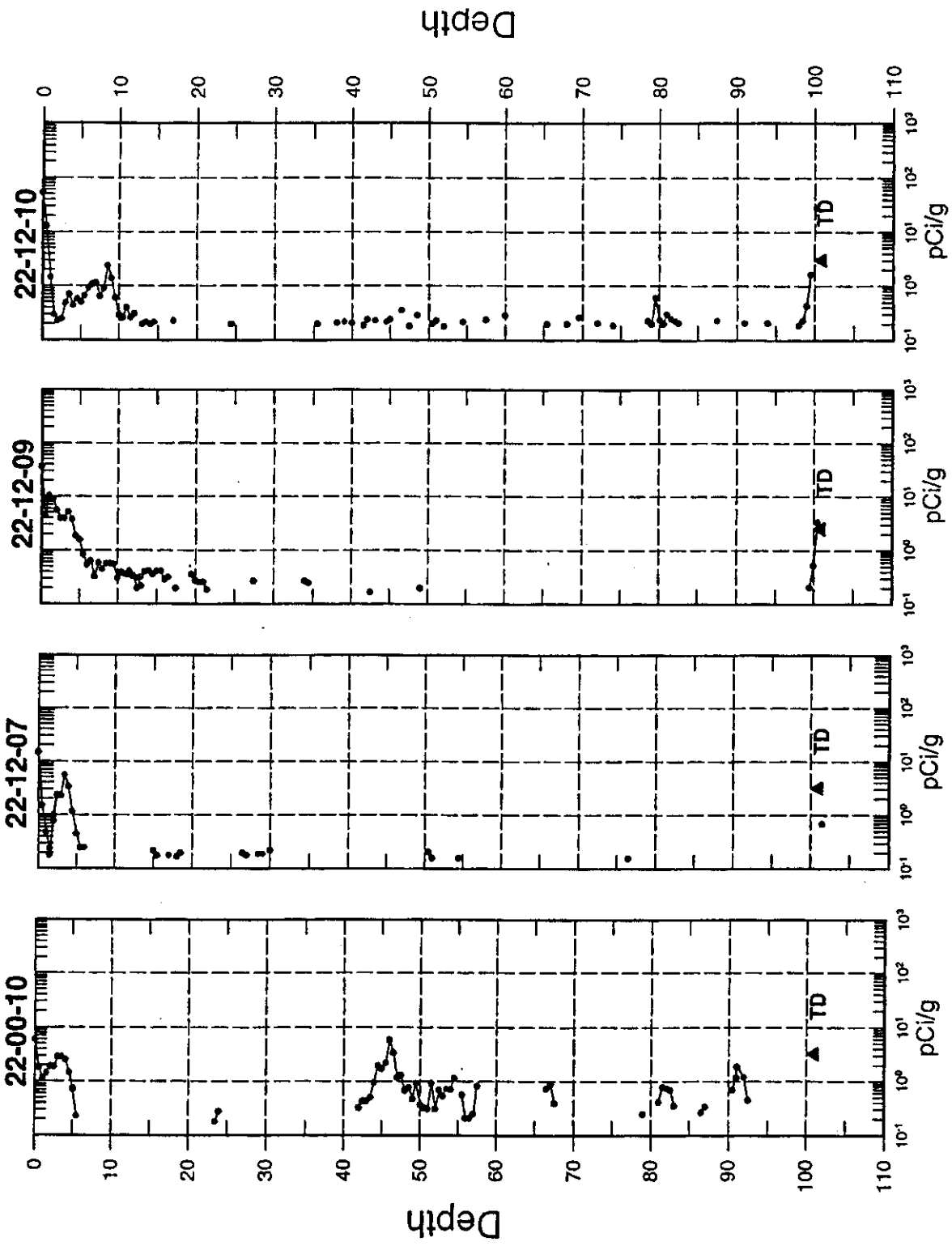


Figure E-40. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-112 (sheet 2).



ANALYSIS OF HISTORICAL GROSS GAMMA LOGGING DATA FROM BX TANK FARM, HNF-3531, REV. 0—SUMMARY

Analysis of Historical Gross Gamma Logging Data from BX Tank Farm

D. A. Myers
Waste Management Northwest/Three Rivers Scientific
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

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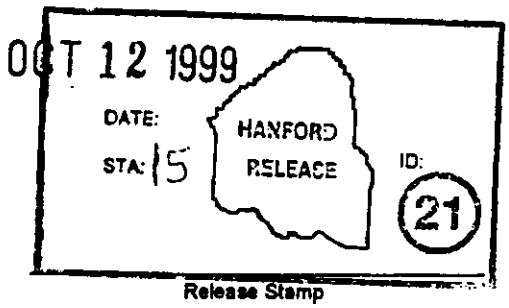
Key Words: Vadose Zone, BX Tank Farm, Dry Well Gross Gamma, Gross Gamma Logs

Abstract: Gross gamma ray logs, recorded from January 1975 through mid-year 1994 as part of the Single-Shell Tank Farm Dry Well Surveillance Program, have been reanalyzed for the BX tank farm to locate the presence of mobile radionuclides in the subsurface. This report presents the BX tank farm gross gamma ray data in such a way as to assist others in their study of vadose zone mechanisms.

Karen M. Noland 10/12/99
Release Approval Date



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2.2. Contaminated:

Identification of specific gamma emitting isotopes that are in the subsurface is attainable from data acquired by the SGLS. Integration of the decay rate of the radionuclide species with the gross gamma ray data collected during the dry well surveillance program provides insight as to the rate of change, if any, of radionuclides in the subsurface. During the analysis of BX Tank Farm data, seven isotopes were identified or hypothesized to occur in radioactive zones. They are cesium-137 (Cs-137), cobalt-60 (Co-60), antimony-125 (Sb-125), uranium-235 and -238 (U-235/8), europium-154 (Eu-154), and ruthenium-106 (Ru-106). The most commonly found isotope is Cs-137, which is often found by itself although it is associated with one or more of the other isotopes in some wells. Uranium-235/8 is also frequently present in the wells east of the tank farm.

Ru-106 is not currently present above the detection threshold in any of the wells examined by the SGLS. This is due to the very rapid exponential decline over a short half-life of 1.02 years. Ru-106 is hypothesized to have been present in 11 wells between 1975 and 1980 on the basis of the gross gamma ray data and the resulting GTP calculations that mimic the decay rate of Ru-106, coupled with the inventory list of known radionuclides for that time period. It must be noted, however, that the method of fitting a decay curve to the observed GTP trend identifies only those contaminants that are not changing. Therefore, it is assumed that Ru-106 is present if the decay curve for Ru-106 matches the GTP plot. If any decay curve does not match, then the contaminants cannot be identified with this method without additional information. The isotopes identified with the SGLS are primarily found to be present under four subsurface conditions: stable, unstable, tank farm activity, and undetermined. The location of wells labeled with the conditions of subsurface zones is shown in Figure 2. A different condition can be indicated for each zone within a well with multiple zones.

2.2.1 Tank Farm Attributed:

An irregular change in the intensity of gross gamma rays between successive surveys at or near the surface suggest that contamination may be the result of tank farm activities or logging procedure changes and not vadose zone mechanics. Radioactive contamination is near the surface in ten wells, apparently as the result of tank farm activities (i.e., logging procedure changes, transfer line operations, valve box and conduit leaks, spills, etc.), and are listed in Table 3. Four of these wells have additional radioactive zones at depth that are categorized according to the rate of change, if any, exhibited by the radionuclides present and are included in the discussions that follow. Well 21-12-02 has tank farm activity apparent at the surface, but it is undetermined as to whether the zone below has been influenced by this activity.

Table 3. BX Tank Farm Activity Zones

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Max. GTP ft*c/s	Year Max. GTP	Isotopes Identified
21-02-01	100	TF Activity	0-5	800	1975	^{137}Cs
21-03-07	95	TF Activity	2-10	4,500	1977	^{137}Cs; ^{106}Ru
21-04-03	100	TF Activity	0-12	6,500	1976	^{137}Cs; ^{154}Eu
21-04-06	100	TF Activity	0-10	50,000	1985	^{137}Cs
21-08-02	130	TF Activity	0-14	8,000	1980	^{137}Cs
21-08-07	100	TF Activity	0-12	300,000	1975	^{137}Cs
21-08-12	100	TF Activity	2-10	2,000	1994	^{137}Cs
21-09-04	100	TF Activity	5-14	10,000	1980	^{137}Cs
21-10-01	100	TF Activity	0-10	200	1975	^{137}Cs
21-12-02	100	TF Activity	0-6	400	1975	^{137}Cs

2.2.2 Undetermined:

Infrequently, the subsurface condition of a zone with radioactive contamination cannot be determined and the zone is therefore classified as undetermined. There are twelve out of 134 zones in the 74 wells examined that are undetermined (Table 4). These zones occur throughout the subsurface and have:

- Data that are too near the threshold for detection limits to determine stability due to statistical noise

- Stable subsurface conditions at the beginning of data collection, whereby an unstable condition develops (indicated by a rate of change that is inconsistent with the decay rate of known isotopes in the well) that does not become stable within the timeframe of data collection.

There is insufficient information available to determine if contamination at depth may be the result of well installation activities.

Usually, the maximum GTP calculated for the gross gamma ray data seems to coincide with the start of digital data collection. There are two exceptions:

- Well 21-08-12 had a maximum GTP calculated for Cs-137 from 2 to 10 feet in 1994 that apparently relates to a tank farm activity event.

- Another exception occurred in well 21-01-01 where the maximum GTP calculated for Co-60 and Sb-125 in the zone from 53 to 60 occurred in 1980.

3.5 Unstable Zones:

Periods of instability were usually short and occurred very early in the timeframe over which digital data were collected. For the unstable zones, data collection often started in while conditions in the zone were still unstable. An exception to this occurs in the depth interval from 53 to 60 feet in well 21-01-01, where there are two distinct periods of increase followed by periods of decrease between 1975 and 1980. See Table 8 for a list of wells that had unstable zones of contamination.

Table 8. BX Unstable Zones

Borehole Number	Change in GTP	Timeframe years	Isotopes Identified	Depth feet
21-00-02	increase	1975-1976	^{137}Cs; ^{a}^{106}Ru	70-80
21-01-01	inconsistent decrease	1975-1977	^{137}Cs	13-23
21-01-01	inconsistent decrease	1975-1985	^{125}Sb	49-53
21-01-01	increase	1975-1976	^{60}Co; ^{125}Sb	53-60
21-01-01	increase	1979-1980	^{60}Co; ^{125}Sb	53-60
21-01-02	increase followed by an inconsistent decrease until 1985	1975-1978/1985	^{137}Cs	5-12
21-01-02	inconsistent decrease[a]	1975-1977	^{60}Co; ^{106}Ru	54-64
21-01-02	increase followed by an inconsistent decrease until mid 1976	1975-1976/1976	^{60}Co; ^{106}Ru	64-72
21-01-02	inconsistent flat decay rate followed by increase until 1985[b]	1975-1980/1985	^{60}Co	72-78
21-02-06	increase followed by an inconsistent decrease until 1979	1975-1975/1979	^{60}Co; ^{106}Ru	34-46
21-03-03	increase	1975-1976	^{106}Ru	60-80
21-04-06	inconsistent decrease	1975-1985	^{137}Cs	8-20
21-04-11	inconsistent decrease	1977-1984	^{137}Cs	2-17
21-05-06	inconsistent decrease	1975-1984	^{137}Cs	2-15

[a]Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, may not be identified if the period of instability is prior to the collection of SGLS data.

[b]There may be some indication of Ru-106 moving down from the zone at 54-64 feet to the zone at 64-72 feet between 1975 and 1977, but more study is necessary and pre-1975 data would be required.

[c]The increase in Co-60 in the zone at 72-78 feet is likely not due to downward movement from the Co-60 in the adjacent interval above since the interval above is stable from 1980 to 1985.

4.0 Special Areas of Interest

4.1 Southwest section of BX Tank Farm (107, 108, 110, 111 Tanks):

Between tanks 108 and 111 are three boreholes:

Table 9. Wells 21-11-03, 21-11-04, and 21-08-07

21-11-03			21-11-04			21-08-07		
Depth feet	Max. GTP ft*c/s	Isotope/ [a]Probe Type	Depth feet	Max. GTP ft*c/s	Isotope/ Probe Type	Depth feet	Max. GTP ft*c/s	Isotope/ Probe Type
0-10	1,000	^{137}Cs/4				0-12	[b]300,000	^{137}Cs/4
34-44	150,000	^{137}Cs/4	35-46	110,000	^{137}Cs/4	30-42	3,500	^{137}Cs, ^{60}Co/4
44-62	1,500	^{137}Cs/4				42-52	1,800	^{137}Cs, ^{60}Co/4
62-70	10,000	^{137}Cs/4						
70-94	5,000	^{137}Cs/4						

[a]Probe type:
4 = NaI, most sensitive, reads lowest level of gamma ray activity.
Caution must be used when relating GTP values in zones recorded with different probe types.

[b]Tank farm activity.

These boreholes are nearly equal distance apart between the tanks (Figure 6). The highest GTP is at 35-45 feet, except for the surface of 21-08-07 at 300,000 ft*c/s GTP, which is apparently due to tank farm activities. Immediately surrounding these wells are wells with significantly lower or no contamination in this zone. The primary isotope present is Cs-137 with Co-60 appearing in the southeast corner of this region. The zone of contamination between tanks 108 and 111 and between tanks 107 and 110 is relatively thin (35 to 50 feet). The contamination in well 21-11-03 exists at the bottom of the well and the surrounding wells do not indicate contamination at this depth. It is not possible to determine the total depth of contamination with the current data, or whether detections are an artifact of the well installation.

Between and to the south of tanks 107 and 110 are three boreholes:

Table 10. Wells 21-10-03, 21-10-05, and 21-07-06

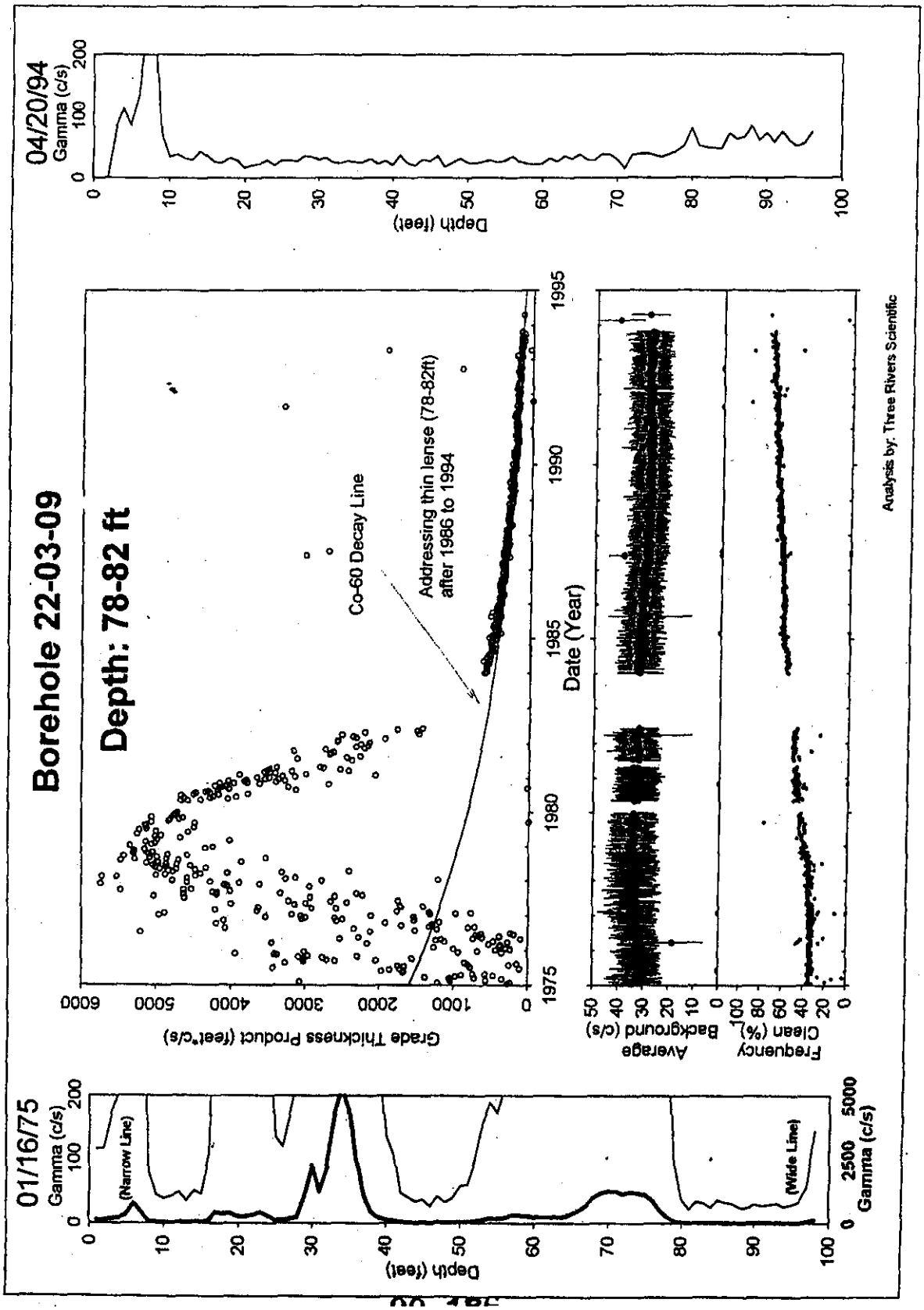
21-10-03			21-10-05			21-07-06		
Depth feet	Max. GTP ft*c/s	Isotope/ [a]Probe Type	Depth feet	Max. GTP ft*c/s	Isotope/ Probe Type	Depth feet	Max. GTP ft*c/s	Isotope/ Probe Type
0-23	30,000	^{137}Cs/2						
23-41	700	^{137}Cs/2				20-34	70,000	^{137}Cs/1
41-57	25,000	^{137}Cs/1	31-52	100,000	^{137}Cs/1	34-53	[b]200,000	^{137}Cs/1
57-72	500	^{137}Cs/1	52-62	4,000	^{137}Cs/1	53-99	50,000	^{137}Cs/1
72-88	8,000	^{137}Cs/1	74-85	600	^{137}Cs/1			
88-95	400	^{137}Cs/1						

[a]Probe type:
1 = Green GM, moderately sensitive; reads moderate levels of gamma ray activity.
2 = Red GM, least sensitive; reads highest level of gamma ray activity.
Caution must be used when relating GTP values in zones recorded with different probe types.

[b]Probe limits exceeded; data unreliable.

Two wells are between tanks 107 and 110 and one is to the south of tank 107 (Figure 6). Contamination has its highest intensity in the zone from 30 to 50 feet with high GTP from surface to 23 feet in well 21-10-03 and 20 to 35 feet in well 21-07-06. Wells immediately surrounding this area have significantly lower or no contamination in these zones. There is not enough information to the south of well 21-07-06 to determine if contamination exists in the subsurface further south. The primary isotope present is Cs-137 with Co-60 appearing to the north of the area in well 21-10-01 in the 30 to 50 foot zone, and Ru-106 appearing further to the northeast in this zone. The contamination in well 21-10-03 exists at the bottom of the well at low concentration and most of the surrounding wells do not have contamination at this depth. Well 21-07-06 does have contamination at this depth, but at a higher concentration. It is not possible to determine the total depth of contamination with the current data, or whether detections are an artifact of the well installation.

Figure E-41. Depth vs. Contaminant Concentration in Borehole 22-03-09.



ANALYSIS OF HISTORICAL GROSS GAMMA LOGGING DATA FROM BY TANK FARM, HNF-3532, REV. 0—SUMMARY

Analysis of Historical Gross Gamma Logging Data from BY Tank Farm

D. A. Myers
Waste Management Northwest/Three Rivers Scientific
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

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Org Code: 73100 Charge Code: ~~106501~~ 110167/CA40 HMLM0131
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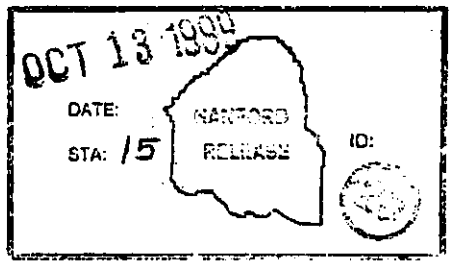
Key Words: Vadose Zone, BY Tank Farm, Dry Well Gross Gamma, Gross Gamma Logs

Abstract: Gross gamma ray logs, recorded from January 1975 through mid-year 1994 as part of the Single-Shell Tank Farm Dry Well Surveillance Program, have been reanalyzed for the BY tank farm to locate the presence of mobile radionuclides in the subsurface. This report presents the BY tank farm gross gamma ray data in such a way as to assist others in their study of vadose zone mechanisms.



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south part of the tank farm, primarily around the 104 tank. Uranium-235/8 is identified in only one well, 22-11-08 from 56 to 66 feet. Europium-154 is identified in only one well, 22-03-09 from 0 to 11 feet.

Ruthenium-106 is not currently present above the detection threshold in any of the wells examined by the SGLS. This is due to the very rapid exponential decline over a short half-life of 1.02 years. Ruthenium-106 is hypothesized to have been present in 17 wells in 1975 and in one well in 1976 on the basis of the gross gamma ray data, the resulting GTP calculations that mimic the decay rate of Ru-106, and the inventory list of known radionuclides for that time period. It must be noted, however, that the method of fitting a decay curve to the observed GTP trend identifies only those contaminants that are not changing. Therefore, it is assumed that Ru-106 is present if the decay curve for Ru-106 matches the GTP plot. If any decay curve does not match, then the contaminants cannot be identified with this method without additional information. The isotopes identified with the SGLS are primarily found to be present under four subsurface conditions: stable, unstable/unstable early, tank farm activity, and undetermined. The location of wells labeled with the conditions of subsurface zones is shown in Figure 2. A different condition can be indicated for each zone within a well with multiple zones.

2.2.1 Tank Farm Activity:

An irregular change in the intensity of gross gamma rays between successive surveys at or near the surface suggest that contamination may be the result of tank farm activities or logging procedure changes and not vadose zone mechanics. Cs-137 exists near the surface in 47 wells, affecting as much as 30 feet below surface, apparently as the result of tank farm activities (i.e., logging procedure changes, transfer line operations, valve box and conduit leaks, spills, etc.). The wells affected by tank farm activities are listed in Table 3. Thirty three of these wells are or appear to be stable from 1986 to the end of gross gamma ray data collection and are labeled as such in the table. Thirty-five wells have additional radioactive zones at depth that are categorized according to the rate of change, if any, exhibited by the radionuclides present and are included in the discussions that follow.

Table 3. BY Tank Farm Activity Zones

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Max. GTP ft*c/s	Year Max. GTP	Isotopes Identified	Comment
22-00-04	100	TF Activity	0-10	200	1975	^{137}Cs	
22-00-10	120	TF Activity	0-10	150	1975	^{137}Cs	
22-01-01	100	TF Activity	0-6	400	1985	^{137}Cs	
22-01-03	100	TF Activity	0-10	100	1975	^{137}Cs	
22-01-04	100	TF Activity	0-15	1,700	1975	^{137}Cs	
22-01-07	100	TF Activity	0-6	6,000	1975	^{137}Cs	
22-01-10	100	TF Activity	0-10	1,500	1975	^{137}Cs	
22-02-01	100	TF Activity	0-10	800	1985	^{137}Cs	
		TF Activity	10-20	200	1984	^{137}Cs	
22-02-02	100	TF Activity	0-6	600	1975	^{137}Cs	
22-02-05	100	TF Activity	0-10	300	1975	^{137}Cs	
22-02-07	150	TF Activity	0-10	200	1986	^{137}Cs	No SGLS; high surface radiation area
22-02-09	100	TF Activity	0-10	400	1986	^{137}Cs	
22-03-01	95	TF Activity	0-10	200	1986	^{137}Cs	
22-03-04	100	TF Activity	0-10	900	1975	^{137}Cs	
		TF Activity	10-30	800	1975	^{137}Cs	
22-03-06	100	TF Activity	0-10	900	1975	^{137}Cs	
22-03-07	100	TF Activity	0-8	100	1975	^{137}Cs	
22-03-08	100	TF Activity	0-8	200	1975	^{137}Cs	
22-03-09	100	TF Activity	0-11	2,000	1975	^{137}Cs; ^{154}Eu	
22-03-10	100-85	TF Activity	0-8	300	1975	^{137}Cs	Borehole filled in to 85 feet in 1980
22-04-09	100-125	TF Activity	0-8	200	1984	^{137}Cs	
22-04-11	100	TF Activity	0-8	200	1984	^{137}Cs	
22-05-01	100	TF Activity	0-10	130,000	1985	^{137}Cs	Some surveys are near count rate limits

22-05-05	100	TF Activity	0-10	120	1975	^{137}Cs	
22-06-01	100	TF Activity	0-8	400	1984	^{137}Cs	Very low levels after 1986
22-06-05	100	TF Activity	0-8	70	1975	^{137}Cs	
22-06-07	140	TF Activity	0-8	200	1984	^{137}Cs	
22-06-11	100	TF Activity	0-10	200	1975	^{137}Cs	
22-07-01	100	TF Activity	0-10	300	1975	^{137}Cs	
22-07-09	100	TF Activity	0-9	2,500	1984	^{137}Cs	
22-07-10	97	TF Activity	0-6	1,500	1975	^{137}Cs	
22-08-01	100	TF Activity	0-12	200,000	1989	^{137}Cs	Count rate may have been exceeded
22-08-02	100	TF Activity	0-10	20,000	1993	^{137}Cs	
22-08-05	100	TF Activity	0-8	200	1975	^{137}Cs	
22-08-06	100	TF Activity	0-8	1,200	1975	^{137}Cs	
		TF Activity	8-18	500	1975	^{137}Cs	
22-08-07	135	TF Activity	0-8	500	1975	^{137}Cs	
22-08-09	100	TF Activity	0-10	80,000	1984	^{137}Cs	
22-08-12	105	TF Activity	0-8	10,000	1989	^{137}Cs	
22-09-02	100	TF Activity	0-10	2,000	1975	^{137}Cs	
		TF Activity	10-14	300	1975	^{137}Cs	
22-09-05	100	TF Activity	0-10	100	1975	^{137}Cs	
22-09-11	100	TF Activity	0-10	1,500	1975	^{137}Cs	
22-10-09	100	TF Activity	0-10	20,000	1975	^{137}Cs	
22-11-01	100	TF Activity	0-5	1,000	1975	^{137}Cs	
		TF Activity	5-10	900	1975	^{137}Cs	
22-11-05	100	TF Activity	0-10	3,000	1975	^{137}Cs	
22-11-08	100	TF Activity	0-10	100	1975	^{137}Cs	
22-11-09	100	TF Activity	0-8	8,000	1975	^{137}Cs	
22-12-03	100	TF Activity	0-10	200,000	1980	^{137}Cs	Count rate limits possibly exceeded
22-12-05	100	TF Activity	0-20	1,000	1975	^{137}Cs	
22-12-06	100	TF Activity	0-20	8,000	1975	^{137}Cs	
22-12-07	100	TF Activity	0-10	1,500	1984	^{137}Cs	Mostly below detection limit except around 1985

*Stable or appears to be stable after 1986.

2.2.2 Undetermined:

Infrequently, the subsurface condition of a zone with radioactive contamination cannot be determined and the zone is therefore classified as undetermined. There are eight zones in seven wells examined that are undetermined (Table 4). These zones occur throughout the subsurface and have:

- Data that are too near or below the threshold for detection limits, or timeframe of data collection is too short to determine stability due to statistical variations
- Possibly been affected by depth shift or surface activities
- An isotope(s) that is not identified through SGLS analysis, and a decay curve for a hypothesized isotope that does not fit the GTP trend
- Data that were collected with inappropriate equipment.

		Stable	46-54	150	1975	^{137}Cs; ^{60}Co
		Stable	54-63	200	1975	^{60}Co
		Stable	63-73	900	1975	^{60}Co
22-09-01	100	Stable	24-35	250	1984	^{106}Ru
		Stable	40-55	2,200	1975	^{125}Sb; ^{106}Ru
22-09-02	100	Stable	14-34	1,200	1975	^{137}Cs
		Stable	42-64	500	1975	^{106}Ru
22-09-05	100	Stable	40-58	250	1975	^{137}Cs; ^{125}Sb
22-09-08	98	Stable	43-52	150	1981	^{60}Co
22-09-11	100	Stable	16-25	300	1975	^{137}Cs; ^{125}Sb
		Stable	25-38	450	1975	^{106}Ru
22-10-05	100	Stable	45-55	200	1975	^{60}Co
22-11-08	100	Stable	56-66	120	1975	^{60}Co; $^{234/6}U$
22-11-09	100	Stable	24-34	450	1975	^{60}Co
22-12-03	100	Stable	10-20	300	1975	^{137}Cs

[a]The decay rate of the isotope(s) identified in the zone matches the change in concentration of the isotope(s) as measured over time, and no noticeable deviation from the match is apparent within the timeframe that gross gamma ray data were collected.

[b]The decay rate of the isotope(s) identified in the zone appears to match the change in concentration of the isotope(s) as measured over time, but stability cannot be rigorously determined.

[c]Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified when SGLS data were obtained.

2.2.4 Unstable:

The condition of a subsurface zone with radioactive contamination is considered unstable when, at some point within the timeframe of data collection, contamination was not decreasing at the decay rate of the isotope(s) identified with SGLS. In this case, the decay curve does not match the trend observed in the GTP of the data. In the BY Tank Farm, 34 zones in 26 wells are identified which exhibit periods of instability early in the timeframe (prior to 1990) that gross gamma ray data were collected. Most of these unstable zones have since developed a consistent rate of decrease through when the last data were collected. Many of the unstable zones have decayed to levels too low to determine stability and are therefore called unstable. Four wells appear to have contamination that has moved below the bottom of the well: 22-03-09, 22-07-02, 22-07-09, and 22-08-02. The estimated rate of movement of the contamination in well 22-03-09 appears to be about 2 feet per year. See Table 6 for list of unstable zones.

Downward movement is seen for the first time in the BY Tank Farm analysis report in 13 wells. Well 22-06-07 also appears to exhibit lateral movement into the zone from 52 to 80 feet. Downward movement is typically identified in the stack plot by an apparent widening of a depth zone of contamination over time. Lateral movement is postulated when the decay curve of isotopes known to be present in the well do not match the GTP plot of the gross gamma ray data and the stack plot does not indicate downward movement. Due to the limited range in distance around the borehole that the logging instruments can record information for, it is not possible to identify if downward movement is restricted to the annulus of the borehole or in the formation adjacent to it. It is also not possible to identify if the contamination is coming from outside of the area of the borehole, or whether it is coming from above or below the contaminated zone within the well area.

22-08-02	100	Unstable	44-62	1975-1994	^{60}Co; $^{*125}Sb$	Decr. 1975-1982 flat near 0 1982-1994
		Unstable	62-72	1975-1994	$^{*125}Sb$	Incr. 1975-1977; decr. 1977-1994
		Unstable	72-84	1975-1994	$^{*125}Sb$	Decr. 1975-1981; incr. 1981-1985; decr. 1985-1994
		Unstable	84-100	1975-1994	$^{*125}Sb$	Decr. 1975-1988; incr. 1988-1991; decr. 1991-1994
22-08-05	100	Unstable early	63-74	1975-1986	^{60}Co	Decr.
		Unstable early	74-84	mid1984-1990	^{60}Co	Incr.
22-08-06	100	Unstable early	73-83	1975-1977	^{60}Co	Flat
22-08-09	100	Unstable early	72-84	1975-1976	^{137}Cs; $^{*106}Ru$	Incr.
22-08-12	105	Unstable early	25-40	1975-1994	^{137}Cs	Incr. 1975-mid1976; decr. mid1976-1978; incr. 1978-mid1980; decr. mid1980-1983; flat near 0 1983-1994
		Unstable early	40-51	1975-1989	^{60}Co; $^{*125}Sb$	Decr.
		Unstable early	51-60	1975-1983	^{60}Co	Decr. 1975-1979; incr. 1979-mid1983
		Unstable early	60-70	1975-1987	^{60}Co	Decr.
		Unstable early	70-82	1975-1983	^{60}Co	Incr.
22-09-07	100	Unstable early	20-40	mid1978-1982	$^{*106}Ru$	Decr.
		Unstable early	40-50	1975-1984	$^{*106}Ru$	Incr. 1975-1976; decr. 1980-1984
		Unstable early	50-64	1980-1990	$^{*125}Sb$; $^{*106}Ru$	Decr.
22-09-11	100	Unstable early	38-52	1975-1976	$^{*106}Ru$	Decr.
22-10-05	100	Unstable early	55-75	1975-1979	^{60}Co	Incr.
22-10-07	100	Unstable early	45-65	1980-1994	^{60}Co	Incr. 1980-1983; decr. 1983-1985; flat near 0 1985-1994
22-10-10	100	Unstable early	58-76	1975-1980	^{60}Co	Decr.
22-11-01	100	Unstable	19-28	1982-1994	^{137}Cs	Incr. 1982-1984; decr. 1984-1994
22-11-09	100	Unstable early	34-46	1975-mid1978	^{60}Co	Flat

*Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified if the period of instability is prior to the collection of SGLS data.

**Unless otherwise noted, the GTP plot decreases consistent with the decay curve of known isotopes.

Table 10. BY Tank Farm Unstable Zone Parameters

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Interval of Instability	Isotopes Identified	**Comment
22-00-02	100	Unstable	64-96	1979-1994	^{60}Co	^{137}Cs decay curve fits, but was not used as ^{137}Cs was not id'd by the SGLS
22-00-03	145	Unstable early	80-117	1975-1976	^{60}Co	
22-03-09	100	Unstable early	24-52	1975-1977	^{60}Co; $^{*125}Sb$; $^{*106}Ru$	Incr. 1975-1976; decr. 1976-1977
		Unstable early	44-52	1975-1984	$^{*106}Ru$	Incr. 1975-1980; sharp incr. 1980-mid 1982
		Unstable	78-92	1975-1985	^{60}Co; $^{*125}Sb$	Incr. 1975-1979; decr. 1979-1985
		Unstable	48-95	1975-1990	^{60}Co	Incr. 1975-1976; stable 1976-1978; unstable decr. 1978-1990; stable 1990-1994
22-04-09	100-125	Unstable early	75-95	1974-1984	^{60}Co	Incr. 1979-1980; decr. 1980-0982; decr. 1982-1984
22-05-09	100	Unstable	55-90	1975-1985	^{60}Co	Decr.
22-06-05	100	Unstable	36-50	1978-1981	^{60}Co; $^{*125}Sb$	Decr.
		Unstable	62-84	1986-mid1991	^{60}Co	Decr.
		Unstable	28-84	1975-mid1975	^{60}Co; $^{*125}Sb$	Incr.
		Unstable	40-84	1979-1994		Decr. mid 1975-1976; decr. 1979-1994
22-06-07	140	Unstable early	40-52	1975-mid1982	^{137}Cs	Decr.
		Unstable early	52-64	1975-1985	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979; decr. 1979-1985
		Unstable early	64-80	1975-1984	^{60}Co	Incr. 1975-1981; decr. 1981-1984
		Unstable early	52-80	1975-mid1979	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979
22-06-09	100	Unstable early	70-90	1976-1976	$^{*106}Ru$	Incr. 1975-mid1975; decr. mid1975-1976
22-07-01	100	Unstable early	40-52	1975-1981	^{137}Cs	Incr. 1975-1976; decr. 1976-1981
22-07-02	100	Unstable early	42-53	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-1984; decr. 1981-1994
		Unstable early	53-70	1975-1994	^{60}Co	Incr. 1975-1979; rapid incr. 1979-early 1979; decr. early 1979-1981; decr. 1981-1994
		Unstable early	70-82	1980-mid1987	^{60}Co	Incr. 1980-1981; decr. 1981-1987
		Unstable early	82-95	1975-1987	^{60}Co	Decr. 1975-1980; incr. 1982-mid1983; decr. mid1983-1987
22-07-05	100	Unstable early	40-57	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-mid1978; incr. mid1978-1979; decr. 1979-1985
		Unstable early	57-65	mid1978-mid1986	^{60}Co	Incr. mid1978-mid1983; decr. mid1983-mid1986
		Unstable early	65-78	1981-mid1987	^{60}Co	Incr.
22-07-07	100	Unstable early	30-54	1980-1994	^{137}Cs; $^{*125}Sb$; $^{*106}Ru$	Step decr. 1980-1981; flat near 0 to 1994
		Unstable	80-98	1975-1985	^{60}Co; ^{125}Sb	Incr. 1975-1976; decr. 1976-1981; incr. 1981-mid1981; decr. mid1981-1985
22-07-09	100	Unstable	62-74	1975-1986	^{137}Cs	Incr. 1975-mid1976; decr. m1976-1986
		Unstable	74-84	1975-mid1988	^{60}Co	Incr. 1975-1979; decr. 1979-mid1980; incr. mid1980-1982; decr. 1982-mid1988
		Unstable	84-94	1982-1989	^{60}Co	Incr. 1982-1986; decr. mid1981-1985; decr. 1985-1994
		Unstable	94-100	1981-1990	^{60}Co	Incr. 1981-mid1981; decr. mid1981-mid1982; incr. 1984-mid1986; decr. mid1986-1990
22-08-01	100	Unstable	59-95	1975-1986	^{60}Co; $^{*125}Sb$	Decr.

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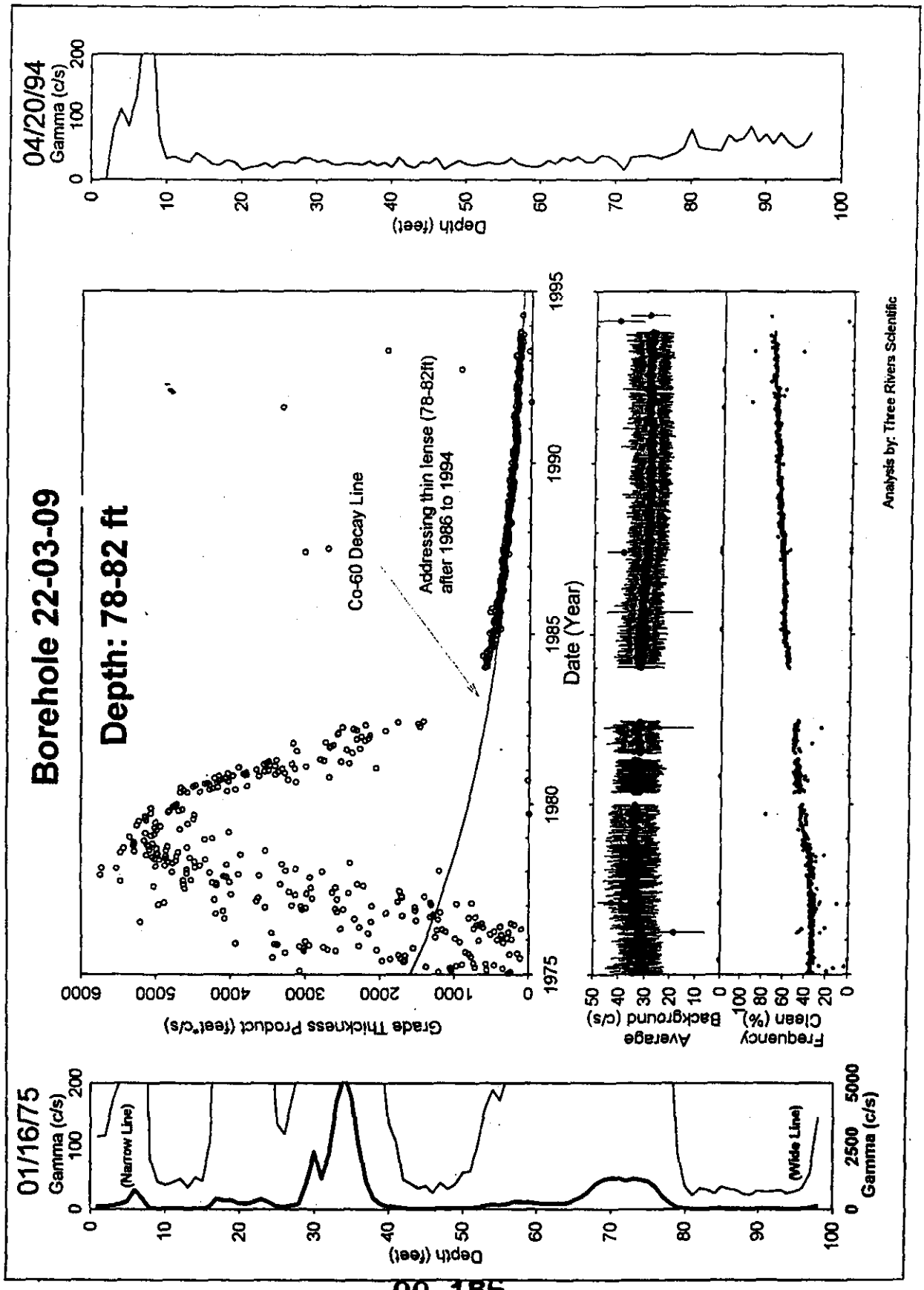
22-08-02	100	Unstable	44-62	1975-1994	^{60}Co; ^{125}Sb	Decr. 1975-1982 flat near 0 1982-1994
		Unstable	62-72	1975-1994	^{125}Sb	Incr. 1975-1977; decr. 1977-1994
		Unstable	72-84	1975-1994	^{125}Sb	Decr. 1975-1981; incr. 1981-1985; decr. 1985-1994
		Unstable	84-100	1975-1994	^{125}Sb	Decr. 1975-1988; incr. 1988-1991; decr. 1991-1994
22-08-05	100	Unstable early	63-74	1975-1986	^{60}Co	Decr.
		Unstable early	74-84	mid1984-1990	^{60}Co	Incr.
22-08-06	100	Unstable early	73-83	1975-1977	^{60}Co	Flat
22-08-09	100	Unstable early	72-84	1975-1976	^{137}Cs; ^{106}Ru	Incr.
22-08-12	105	Unstable early	25-40	1975-1994	^{137}Cs	Incr. 1975-mid1976; decr. mid1976-1978; incr. 1978-mid1980; decr. mid1980-1983; flat near 0 1983-1994
		Unstable early	40-51	1975-1989	^{60}Co; ^{125}Sb	Decr.
		Unstable early	51-60	1975-1983	^{60}Co	Decr. 1975-1979; incr. 1979-mid1983
		Unstable early	60-70	1975-1987	^{60}Co	Decr.
		Unstable early	70-82	1975-1983	^{60}Co	Incr.
22-09-07	100	Unstable early	20-40	mid1978-1982	^{106}Ru	Decr.
		Unstable early	40-50	1975-1984	^{106}Ru	Incr. 1975-1976; decr. 1980-1984
		Unstable early	50-64	1980-1990	^{125}Sb; ^{106}Ru	Decr.
22-09-11	100	Unstable early	38-52	1975-1976	^{106}Ru	Decr.
22-10-05	100	Unstable early	55-75	1975-1979	^{60}Co	Incr.
22-10-07	100	Unstable early	45-65	1980-1994	^{60}Co	Incr. 1980-1983; decr. 1983-1985; flat near 0 1985-1994
22-10-10	100	Unstable early	58-76	1975-1980	^{60}Co	Decr.
22-11-01	100	Unstable	19-28	1982-1994	^{137}Cs	Incr. 1982-1984; decr. 1984-1994
22-11-09	100	Unstable early	34-46	1975-mid1978	^{60}Co	Flat

*Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified if the period of instability is prior to the collection of SGLS data.

**Unless otherwise noted, the GTP plot decreases consistent with the decay curve of known isotopes.


Borehole 22-03-09
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04/20/94
Gamma (c/s)
Depth (feet)
Co-60 Decay Line
Addressing thin lense (78-82ft) after 1986 to 1994
Grade Thickness Product (feet*c/s)
Date (Year)
Average Background (c/s)
Frequency Clean (%)
Analysis by: Three Rivers Scientific
01/16/75
Gamma (c/s)
(Narrow Line)
(Wide Line)
Gamma (c/s)
Depth (feet)

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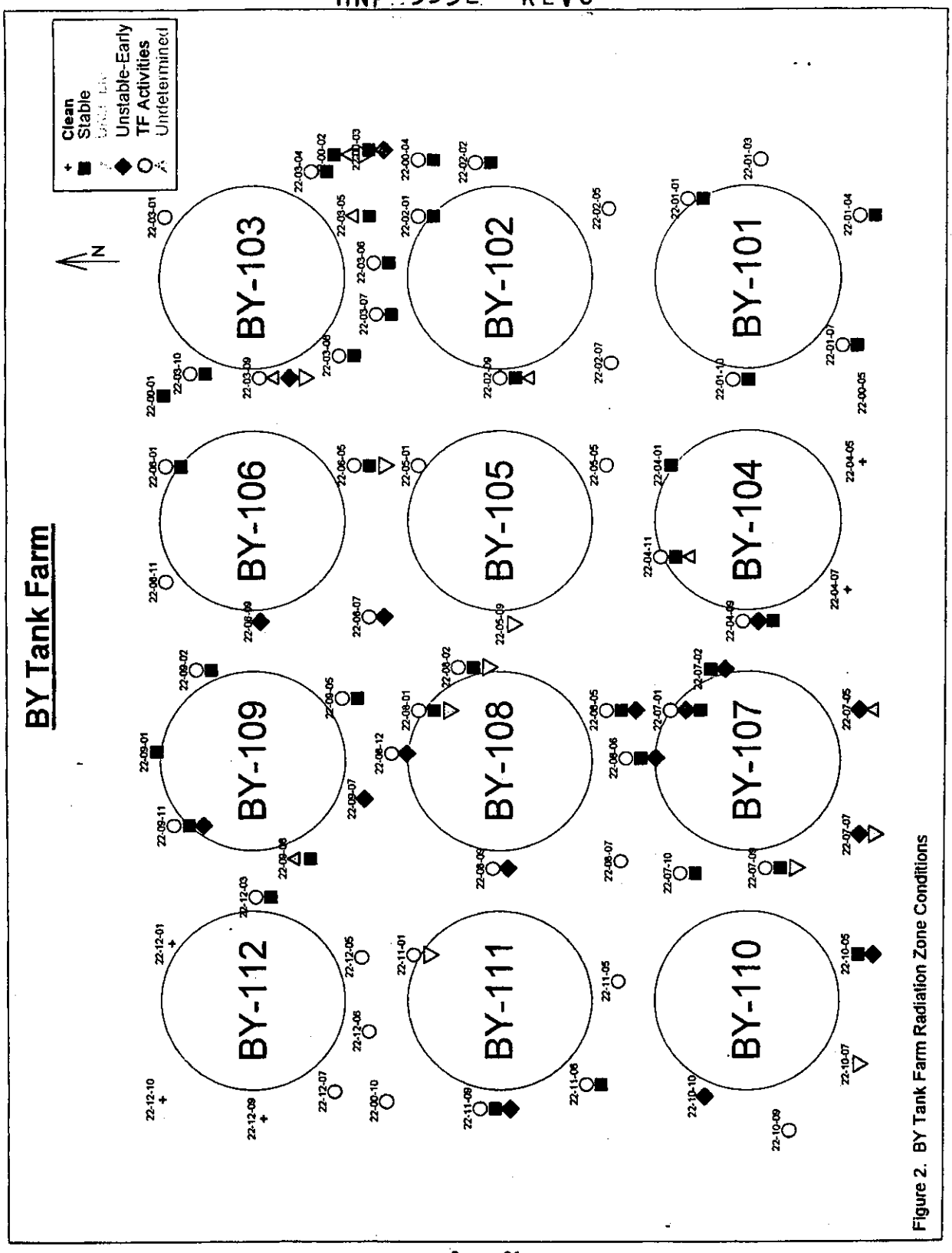

Figure 2. BY Tank Farm Radiation Zone Conditions

Table 6. BY Unstable Zones

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Max. GTP ft*c/s	Year Max. GTP	Isotopes Identified	Comment
22-00-02	100	Unstable	64-96	1,800	1975	^{60}Co	Downward movement at low levels
22-00-03	145	Unstable early	80-117	12,000	1975	^{60}Co	
22-03-09	100	Unstable early	24-52	29,000	1976	^{60}Co; $^{*125}Sb$; $^{*106}Ru$	
		Unstable	48-95	16,000	1976	^{60}Co; $^{*125}Sb$	Downward movement below bottom of well in 1993. Appears to be moving at an estimated rate of 2 feet per year
22-04-09	100-125	Unstable early	75-95	1,800	1980	^{60}Co	
22-05-09	100	Unstable early; undetermined late	55-90	1,000	1975	^{60}Co	Downward movement
22-06-05	100	Unstable	40-84	10,000	1984	^{60}Co; $^{*125}Sb$	Downward movement
22-06-07	140	Unstable early	40-52	300	1975	^{137}Cs	
		Unstable early	52-80	1,100	1979	^{60}Co	Downward and lateral movement
22-06-09	100	Unstable early	70-90	650	1975	$^{*106}Ru$	
22-07-01	100	Unstable early	40-52	800	1976	^{137}Cs	
22-07-02	100	Unstable early	42-95	2,800	1976	^{60}Co	May be downward movement along casing; contaminant may be below bottom of well
22-07-05	100	Unstable early	40-78	3,800	1975	^{60}Co	Downward movement within the zone from 42 to 65 feet
22-07-07	100	Unstable early	30-54	2,500	1975	^{137}Cs; $^{*125}Sb$; $^{*106}Ru$	
		Unstable	80-98	1,800	1976	^{60}Co; ^{125}Sb	Stable since 1983 or 1990
22-07-09	100	Unstable	62-100	2,200	1976	^{137}Cs; ^{60}Co	Downward movement to below well bottom in 1990
22-08-01	100	Unstable	59-95	12,000	1975	^{60}Co; $^{*125}Sb$	Movement of isotopes is unclear; stable from 1985 to 1994
22-08-02	100	Unstable	44-100	15,000	1975	^{60}Co; $^{*125}Sb$	Downward movement, possibly below bottom of borehole
22-08-05	100	Unstable early	63-84	900	1975	^{60}Co	Downward movement
22-08-06	100	Unstable early	73-83	450	1975	^{60}Co	Levels too low to identify downward movement
22-08-09	100	Unstable early	72-84	150	1975	^{137}Cs; $^{*106}Ru$	
22-08-12	105	Unstable early	25-40	300	1980	^{137}Cs	^{137}Cs decay curve does not fit GTP plot
		Unstable early	40-51	3,000	1975	^{60}Co; $^{*125}Sb$	
		Unstable early	51-60	3,000	1975	^{60}Co	Possible downward movement
		Unstable early	60-82	1,000	1976	^{60}Co	Downward movement within the zone
22-09-07	100	Unstable early	20-40	12,000	1975	$^{*106}Ru$	
		Unstable early	40-50	9,000	1976	$^{*106}Ru$	
		Unstable early	50-64	2,700	1976	$^{*125}Sb$; $^{*106}Ru$	
22-09-11	100	Unstable early	38-52	3,500	1975	$^{*106}Ru$	
22-10-05	100	Unstable early	55-75	300	1979	^{60}Co	
22-10-07	100	Unstable early	45-65	200	1983	^{60}Co	
22-10-10	100	Unstable early	58-76	1,500	1975	^{60}Co	
22-11-01	100	Unstable	19-28	4,000	1984	^{137}Cs	
22-11-09	100	Unstable early	34-46	250	1975	^{60}Co	

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Table 10. BY Tank Farm Unstable Zone Parameters

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Interval of Instability	Isotopes Identified	**Comment
22-00-02	100	Unstable	64-96	1979-1994	^{60}Co	^{137}Cs decay curve fits, but was not used as ^{137}Cs was not id'd by the SGLS
22-00-03	145	Unstable early	80-117	1975-1976	^{60}Co	
22-03-09	100	Unstable early	24-52	1975-1977	^{60}Co; $^{*125}Sb$; $^{*106}Ru$	Incr. 1975-1976; decr. 1976-1977
		Unstable early	44-52	1975-1984	$^{*106}Ru$	Incr. 1975-1980; sharp incr. 1980-mid 1982
		Unstable	78-92	1975-1985	^{60}Co; $^{*125}Sb$	Incr. 1975-1979; decr. 1979-1985
		Unstable	48-95	1975-1990	^{60}Co	Incr. 1975-1976; stable 1976-1978; unstable decr. 1978-1990; stable 1990-1994
22-04-09	100-125	Unstable early	75-95	1974-1984	^{60}Co	Incr. 1979-1980; decr. 1980-0982; decr. 1982-1984
22-05-09	100	Unstable	55-90	1975-1985	^{60}Co	Decr.
22-06-05	100	Unstable	36-50	1978-1981	^{60}Co; $^{*125}Sb$	Decr.
		Unstable	62-84	1986-mid1991	^{60}Co	Decr.
		Unstable	28-84	1975-mid1975	^{60}Co; $^{*125}Sb$	Incr.
		Unstable	40-84	1979-1994		Decr. mid 1975-1976; decr. 1979-1994
22-06-07	140	Unstable early	40-52	1975-mid1982	^{137}Cs	Decr.
		Unstable early	52-64	1975-1985	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979; decr. 1979-1985
		Unstable early	64-80	1975-1984	^{60}Co	Incr. 1975-1981; decr. 1981-1984
		Unstable early	52-80	1975-mid1979	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979
22-06-09	100	Unstable early	70-90	1976-1976	$^{*106}Ru$	Incr. 1975-mid1975; decr. mid1975-1976
22-07-01	100	Unstable early	40-52	1975-1981	^{137}Cs	Incr. 1975-1976; decr. 1976-1981
22-07-02	100	Unstable early	42-53	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-1984; decr. 1981-1994
		Unstable early	53-70	1975-1994	^{60}Co	Incr. 1975-1979; rapid incr. 1979-early 1979; decr. early 1979-1981; decr. 1981-1994
		Unstable early	70-82	1980-mid1987	^{60}Co	Incr. 1980-1981; decr. 1981-1987
		Unstable early	82-95	1975-1987	^{60}Co	Decr. 1975-1980; incr. 1982-mid1983; decr. mid1983-1987
22-07-05	100	Unstable early	40-57	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-mid1978; incr. mid1978-1979; decr. 1979-1985
		Unstable early	57-65	mid1978-mid1986	^{60}Co	Incr. mid1978-mid1983; decr. mid1983-mid1986
		Unstable early	65-78	1981-mid1987	^{60}Co	Incr.
22-07-07	100	Unstable early	30-54	1980-1994	^{137}Cs; $^{*125}Sb$; $^{*106}Ru$	Step decr. 1980-1981; flat near 0 to 1994
		Unstable	80-98	1975-1985	^{60}Co; ^{125}Sb	Incr. 1975-1976; decr. 1976-1981; incr. 1981-mid1981; decr. mid1981-1985
22-07-09	100	Unstable	62-74	1975-1986	^{137}Cs	Incr. 1975-mid1976; decr. m1976-1986
		Unstable	74-84	1975-mid1988	^{60}Co	Incr. 1975-1979; decr. 1979-mid1980; incr. mid1980-1982; decr. 1982-mid1988
		Unstable	84-94	1982-1989	^{60}Co	Incr. 1982-1986; decr. mid1981-1985; decr. 1985-1994
		Unstable	94-100	1981-1990	^{60}Co	Incr. 1981-mid1981; decr. mid1981-mid1982; incr. 1984-mid1986; decr. mid1986-1990
22-08-01	100	Unstable	59-95	1975-1986	^{60}Co; $^{*125}Sb$	Decr.

22-08-02	100	Unstable	44-62	1975-1994	^{60}Co; $^{*125}Sb$	Decr. 1975-1982 flat near 0 1982-1994
		Unstable	62-72	1975-1994	$^{*125}Sb$	Incr. 1975-1977; decr. 1977-1994
		Unstable	72-84	1975-1994	$^{*125}Sb$	Decr. 1975-1981; incr. 1981-1985; decr. 1985-1994
		Unstable	84-100	1975-1994	$^{*125}Sb$	Decr. 1975-1988; incr. 1988-1991; decr. 1991-1994
22-08-05	100	Unstable early	63-74	1975-1986	^{60}Co	Decr.
		Unstable early	74-84	mid1984-1990	^{60}Co	Incr.
22-08-06	100	Unstable early	73-83	1975-1977	^{60}Co	Flat
22-08-09	100	Unstable early	72-84	1975-1976	^{137}Cs; $^{*106}Ru$	Incr.
22-08-12	105	Unstable early	25-40	1975-1994	^{137}Cs	Incr. 1975-mid1976; decr. mid1976-1978; incr. 1978-mid1980; decr. mid1980-1983; flat near 0 1983-1994
		Unstable early	40-51	1975-1989	^{60}Co; $^{*125}Sb$	Decr.
		Unstable early	51-60	1975-1983	^{60}Co	Decr. 1975-1979; incr. 1979-mid1983
		Unstable early	60-70	1975-1987	^{60}Co	Decr.
		Unstable early	70-82	1975-1983	^{60}Co	Incr.
22-09-07	100	Unstable early	20-40	mid1978-1982	$^{*106}Ru$	Decr.
		Unstable early	40-50	1975-1984	$^{*106}Ru$	Incr. 1975-1976; decr. 1980-1984
		Unstable early	50-64	1980-1990	$^{*125}Sb$; $^{*106}Ru$	Decr.
22-09-11	100	Unstable early	38-52	1975-1976	$^{*106}Ru$	Decr.
22-10-05	100	Unstable early	55-75	1975-1979	^{60}Co	Incr.
22-10-07	100	Unstable early	45-65	1980-1994	^{60}Co	Incr. 1980-1983; decr. 1983-1985; flat near 0 1985-1994
22-10-10	100	Unstable early	58-76	1975-1980	^{60}Co	Decr.
22-11-01	100	Unstable	19-28	1982-1994	^{137}Cs	Incr. 1982-1984; decr. 1984-1994
22-11-09	100	Unstable early	34-46	1975-mid1978	^{60}Co	Flat

*Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified if the period of instability is prior to the collection of SGLS data.

**Unless otherwise noted, the GTP plot decreases consistent with the decay curve of known isotopes.